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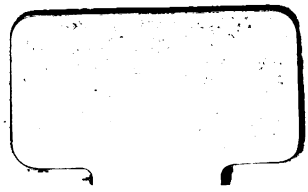

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LI.

SESSION 1877-78.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. xlix., p. 346, line 16, for "Bricha" read "Bricka."

„ p. 355, line 2, for "Grostowsky" read "Grotowsky."

Vol. l., p. 63, line 5, for "28 and 30 *lbs.*" read "28 and 30 *tons.*"

„ p. 149, line 2 from bottom, for "concrete *bearings*" read "concrete *heartings.*"

„ p. 153, line 4 from bottom, for "*the year* ending" read "*the half-year* ending."

„ p. 158, line 17, for "*both coatings*" read "*each coating.*"

„ p. 160, line 4, for "*cubic* yards" read "*lineal* yards."

„ p. 253, line 13 from bottom, for "(about $\frac{1}{10}$ inch)" read "(about $\frac{1}{8}$ inch)."

„ p. 255, line 4, for "*fathoms* (7 *feet*)" read "*feet.*'

„ „ line 6, for the sign of equality in the equation substitute the sign of multiplication.

„ „ line 10, for "24 *to* 523 *fathoms*" read "167·6 *to* 3667·7 *feet.*"

„ p. 280, line 18, for "xxii." read "xxiii."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1877-78.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

November 13, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

IT was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred JAMES BISSET, GEORGE BOHN, EDMUND SMALL CATHELS, WILLIAM LANGTON COKE, GEORGE COOPER, HENRY ALGERNON SHRAPNEL FENNER, WILLIAM GREY FERRAR, RICHARD GARRETT, HENRY JOHNSON, GEORGE KNOWLES, CHARLES LEAN, ALFRED PENNY, WILLIAM GEORGE SCOTT, GEORGE KELSON STOTHERT, WILLIAM CAWTHORNE UNWIN, B.Sc., IRWINE JOHN WHITTY, and CORBET WOODALL from the class of Associate to that of Member.

Also that, under the provisions of Sect. IV. of the Bye-Laws, the following Candidates, having been duly recommended, had been admitted as Students of the Institution:—ALFRED DYKE ACLAND, JAMES GEORGE WILLCOX ALDRIDGE, ROBERT ALEXANDER BRIGGS, ERNEST AUGUSTUS BRINE, FRANCIS CRAWFORD CAFFIN, JOHN FORBES CLOSE, GEORGE WILLIAM DISNEY, WYNNE HOWARD EDWARDS, LEWIS FREDERICK EVELEGH, EDWARD BROCKLEHURST FIELDEN, GERALD FITZGIBBON, ROBERT FITZGIBBON, GEORGE WILLIAM HERSEY, PERCY WILLIAM MONCKTON HOLT, JOHN WYKEHAM JACOMB HOOD, HENRY EDMUND KITSON, ARTHUR HUNTINGTON LEAF, ALEXANDER MACLACHLAN, FRANK NELSON, WILLIAM VYE PADDON, HENRY PARKES, HUGH FREDERICK PERKINS, SAMUEL SYDNEY PLATT, WILLIAM JAMES ROBSON, THOMAS PARR SEVERN, WALTER EDWARD SLADE, HENRY SNELL, ALFRED SUMMERSCALE, JOHN HENRY TUDSBURY TURNER, MONTAGU ALEXIS POLLARD URQUHART, DELFIN VIEYRA, WILHEM WILLINK, FRED WORSNOP, and THOMAS HERBERT WRIGHT.

No. 1,511.—"Review of the Progress of Steam Shipping during the last Quarter of a Century." By ALFRED HOLT, M. Inst. C.E.[1]

THE last five-and-twenty years have witnessed a revolution in the carrying trade of the world, and more particularly in that of this country, which only those who have been engaged in affairs connected with it can completely appreciate. It has been said that up to the moment of railways, an Englishman of the nineteenth century had no better mode of traversing the earth than a Roman of the time of Julius Cæsar, and up to the steamboat epoch, the same might with reasonable accuracy have been said for travel at sea; on neither element had the mode of travel changed, though it might have improved. There was, however, this marked difference between the application of steam to land carriage, and its application to water carriage, that whereas, in the former, its suitability to the conveyance of goods was at once recognised, and was indeed its original purpose, in the latter that use succeeded a long period during which it was applied only to the carriage of passengers and correspondence. The steam navigation of the Atlantic began about 1838, and that of the Mediterranean at an earlier date; but till the period at which this review commences, twenty-five years ago, or 1852, in neither case was the old mode of conveyance for cargo by sailing vessel seriously invaded by the new. From that date a revolution has been witnessed, which has never, it is believed, received the attention it deserves. Broadly stated, and with some considerable exceptions, British carriage by sea has passed from the hands of sailing vessels to steamers. This extension was, in its early days, greatly encouraged by the lavish rates of freight paid by the English and French Governments for the charter of steamers during the Crimean war. At that time the capital embarked in a steamer was in many instances entirely repaid in twelve months, and this return naturally induced increased investments.

Three great changes of construction, from that which was accepted twenty-five years ago, have rendered possible the extension thus referred to. They are: (1) The screw propeller. (2) The iron vessel. (3) The compound engine. All were known, and the first and second were in moderate use, at the beginning of the time; but none had received that firm, unhesitating acceptance

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

which is a necessary prelude to general adoption. And, although the combination of the three in the modern iron screw steamer has constituted a wonderfully economical carrier, yet it should be recollected that its peculiar merits appear only in deep water. Without any of these features, the wooden paddle-wheel vessel, with non-condensing engines, moves immense masses of bulky and weighty cargo on the western rivers of America, at rates of freight at which it would appear impossible to live; and very fine wooden "propellers" (as screw steamers are called in the United States), with single cylinders, maintain their ground in the coasting trade against the iron vessel with the compound engine.

(1.) The peculiar merits of the screw propeller seem to resolve themselves into three. (*a*) It is equally effective at varying draughts. (*b*) It is indifferent to rolling. (*c*) It is capable of being used for the application of either small or great powers. This last peculiarity has more to do than is usually thought with its general adoption. It is equally adapted to be the instrument for propelling the 8-knot collier and the 16-knot White Star boat—which could not be said of the paddle-wheel. The application of low power by means of paddles would be so wasteful as to be practically impossible.

(2.) The main contribution which the use of iron has rendered to the production of an economical carrier by sea has been that, owing to the diversity of form in which it can be produced, the ease of uniting different pieces one to another, and the great strength of such union, it has been possible to construct vessels of much greater displacement, in proportion to the power required for propelling them, than can be done in wood. Many very seaworthy vessels now built of iron could not be built of wood. In endeavouring to form a vessel of the greatest displacement and the least resistance, naturally enough, as every vessel must have two ends, and can only have one middle, and as it is the middle that carries and pays, the first idea was to make that middle as large as possible—in other words, to lengthen the vessel. This process of lengthening has gone through several interesting phases both in old and new vessels. A length of about seven breadths was considered appropriate in 1852, and for some years thereafter a vessel of eight breadths was thought to err on the side of length. This was followed by a somewhat sudden change of opinion, initiated mainly by Messrs. Bibby, of Liverpool, and by Messrs. Harland and Wolff, of Belfast, and a great and rapid stride was made to ten, or even eleven breadths. The merits of this additional length, in giving increased profits to those who adopted it, were so

apparent that a species of mania set in for lengthening vessels. This was between the years 1868 and 1872; and to so great an extent was it carried in Liverpool, that the Mersey Docks and Harbour Board were compelled, on the ground that their graving docks were for repairs only, to refuse the use of them for lengthening. Gradually discoveries were made, in connection with this great length, of points which had previously not been suspected, or, if suspected, had been disregarded. Great length was found to be appropriate only for very large vessels; a 500-ton vessel of eleven beams would hardly look safe to go to sea, while a 5,000-ton vessel of those proportions is a most magnificent and seaworthy structure. Again, although length provides easily driven displacement, a long vessel requires more freeboard in proportion to her depth, a great diminution of her carrying power when weight cargoes have to be considered, and, lastly, the scantling of longitudinal materials for a long vessel is necessarily so much heavier than for a short one, that the weight and cost of the vessel herself come to form a serious element in the calculation. These considerations, in conjunction with the greater handiness of short vessels, have rather turned the tide, and the present phase of opinion is not towards lengthening, but somewhat the opposite. Probably the most economical carriers issue from the north-eastern ports, for such trades as the Baltic, or for the conveyance of grain from the Black Sea, and these are taking somewhat the following proportions:—Length about $7\frac{3}{4}$ times the beam, and depth about $\frac{5}{8}$ to $\frac{3}{4}$ thereof. These vessels have an engine of about 1 nominal HP. to 10 tons of the gross register tonnage, and realise an average speed of about $8\frac{1}{2}$ knots per hour.

(3.) Although, without the screw propeller and the iron vessel, the compound engine would not, single-handed, have given the steamship the hold it has attained, yet, in apportioning the merit amongst the three, the largest share seems to be attributable to it. As with the others there was no novelty, no invention, in the proper sense of the word, but merely an application of long-enunciated ideas to appropriate purposes. No doubt the three properties of steam—direct pressure, expansion, and condensation—can be utilised for the production of power more economically in one cylinder than in two or more; but the circumstances suiting such application rarely present themselves afloat at all, and more rarely still in the screw vessel. A long stroke, a deliberate movement of parts, and an arrangement of valves admitting great range of expansion, and therefore somewhat complicated in details, are necessary. The first and second are not to be obtained, and the

third is inadmissible, in a screw steamer; but where these can be obtained, as in the walking-beam engine of the American paddle-wheel boat, the duty performed for the fuel consumed approaches very nearly to that of the best compound engines made in this country, although the pressures are much less. It is noteworthy how the Americans have held to the single cylinder throughout, and the success they have had with it even in propellers. There is a laudable, and frequently most successful, daring in their designs, which it would be well to profit by; and it is matter of reasonable speculation, whether the compound may not yet be abandoned, and a return made to the single-cylinder engine, modified in details to suit high-pressure steam.

Historically, the facts of the case seem to be as follow:—

In 1852 such screw steamers as then existed were provided with jet condensers, and carried about 15 lbs. to 20 lbs. steam pressure. A dread of high piston speed seemed to prevail, and either very short-stroke direct-acting engines were used, or engines with multiplying gear. Either of these consumed from 4 lbs. to 5½ lbs. of coal per indicated HP. per hour. As time went on the length of stroke was increased, and the cheese-shaped cylinders—at best wasteful abortions—were changed with great advantage for others, and the geared engine became rarer. It is remarkable, bearing in mind that it was originally thought the only possible arrangement, how completely multiplying gear has vanished. The pressures also continued to increase, an economy was effected by superheating the steam, and occasionally surface condensers were employed in the higher class of boats, and many improvements of detail became usual. This type of engine was at its best about 1864 and 1865. It was certain in action, easy to attend to, and durable in its parts. No wonder many engineers regret its disappearance. With it unsubsidised vessels had begun to ply to North America, and the Mediterranean; nearer trades were fully occupied, and it stretched tentatively in vessels of moderate power to the West Indies and the East Coast of South America. The consumption of fuel in good specimens of this engine was, perhaps, just under 4 lbs. of coal per indicated HP. per hour.

This consumption, however, was too great for longer voyages to be remunerative, if exclusively supported by freight and passage money. The attention of engineers was therefore naturally turned to the economy evidently attainable by the use of high-pressure steam. To use it in a single cylinder seemed perilous to the fabric of the engine; and to render the strain equable, the expedient was resorted to of employing the great pressure in a small cylinder,

and the small pressure in a large one. For years Messrs. Randolph and Elder had been constructing engines on this principle with marked economy, and if the pressures were not so great as those coveted, the higher strains entailed by these higher pressures could be managed by using smaller cylinders than they had done. To that firm must be attributed the introduction of the compound engine for marine purposes. The vessels built by Messrs. Randolph and Elder, being mainly engaged in the Pacific Ocean, did not attract the notice they deserved, so that the invention, or rather application, was for a while experimental, and had no general acceptance till about the year 1869. Then the system became pretty thoroughly understood, and the Suez Canal opening the way to the East, "the hour and man" seemed to come together, and the tide set in, which has been flowing, with some fluctuations, but on the whole steadily, ever since. The magnitude of its current and the changes brought about have been touched upon. It will be interesting now to notice the engineers' side of the question, namely, the peculiarities of construction and the economical results of this machine.

The leading feature of the compound engine has been the possession of two cylinders, the same steam being used in both, but under different conditions. The arrangement which has found most favour has been the inverted type, with the cylinders alongside each other, and the cranks coupled generally at right angles. It will be at once seen, that this does not provide for an uninterrupted flow of expansion, and that it is really only a single engine, though with two cranks. Instances are not wanting of difficulty in starting and reversing; nevertheless, the first has not prevented a high economy being developed, nor has the second amounted to a really serious objection in practice. It is supposed that there are more compound engines of this type in existence than of all others put together. Another arrangement, and one that is coming much into vogue for large engines, is that with four cylinders in two pairs, each pair concentric, generally with the high-pressure cylinder on the top, and having one common piston-rod. An excellent engine is thus made, at once providing for perfect expansion and unfailing handling. It has been exclusively employed in the boats of the White Star Line, and from the possibility of obtaining a large power without castings of extraordinary weight or complexity, is at present looked on with great favour. It is also the easiest form into which to "compound" an engine of the old type. There are many other arrangements, some with combined horizontal and vertical cylinders, others with three cylinders,

and a considerable number with two cylinders arranged as a single engine, one crank and a fly-wheel. As fresh water, or an approach thereto, is absolutely necessary for high-pressure boilers, surface condensers are employed, and the cooling surface is generally provided in small thin brass tubes. The boilers vary in design, though hardly to the same extent as the engines, the general type being similar (with the modifications necessitated by the higher pressure) to the old low-pressure boiler. This is too well known to need description; it is internally fired with a combustion chamber at the back of the furnace, and return tubes to the chimney foot over the furnace mouth.

The consumption of the best specimens of such engines as have been described varies from a little under 2 lbs. to 2½ lbs. of good coals per indicated HP. per hour; and though it would be too much to say that no further economy will take place, yet it may reasonably be asserted, that unless some great discovery, involving the production of power from a new source, or the utilisation of the remaining properties of steam, all increased economy must be sought in higher pressures, change of proportions, and improvements of detail. There is no finality in mechanical invention, but there is less future scope as each improvement is realised. Twenty-five years ago twice as much fuel was required as is now burnt; if in the next twenty-five years 20 per cent. further reduction takes place, it is as much as the Author hopes for. There is almost less incentive to further economy today than there once was; for, viewed from the side of the owner's pocket, coals are no longer the chief item of expenditure: his attention is turned to other and heavier disbursements in which to effect a saving—wages, dues, insurance, repairs, &c.

The indicator diagram is generally accepted as a test of the power developed by an engine, and expressing as it does the elements of power—namely, distance, time, and pressure—it seems unreasonable to cavil at its acceptance, and illogical to question its results. Nevertheless, the Author, somewhat diffidently, advances the opinion that, as a test of useful effect, it is not implicitly to be relied on; and as a criterion whereon to fix the purchasing price of an engine, it affords undesirable opportunities of departing from the most useful form. As an instrument to find out faults, the value of the indicator is considerable; as a gauge of the propulsion imparted to a ship, its results are often questionable.

As the compound engine has settled into general acceptance, many fears which once surrounded it have been dissipated, and

it is now equally manageable and durable with any of its predecessors. To preserve the boilers, the engines were at one time made as tight as a still, any waste from escapes being replaced with fresh water obtained by distillation, so that almost the identical water was carried voyage after voyage. This had no better result than the premature decay of the boilers, which when not so well cared for, are apparently more durable. It was found at once easier and less injurious to use sea-water to replace waste; when so treated, and managed with equal care, the high-pressure boiler of the compound engine seems to last as many years as those of the old low-pressure type. The somewhat abstruse question of the use of jacketed cylinders has practically received an adverse solution; for, whatever be the merits of the controversy, the economy was imperceptible, while the complexity of the castings, and the consequent risk of accident, formed at all times a distinct objection.

The shipowner, looking at the commercial side of the question, and not wanting an engine for scientific demonstration, but for practically propelling a ship, will naturally select that description which does it best on the whole; and if he finds one engine, though burning slightly less fuel than another, outbalances that saving by being more costly to buy and keep in repair, will naturally prefer the second. Thus simplicity, accessibility, freedom from likelihood of derangement, and ease of repair are becoming daily more marked features in the steamboat engine, even if these entail slight departures from the most economical form. It is found that anything that can go wrong at sea generally does go wrong sooner or later, so it is not to be wondered that owners prefer the safe to the scientific. It is also found that it is almost as bad to have too many parts as too few; that arrangements which are for exceptional and occasional use are rarely available when wanted, and have the disadvantage of requiring additional care. Their very presence, too, seems in effect to indispose the engineer to attend to essentials. Sufficient stress can hardly be laid on the advantages of simplicity. The human factor cannot be safely neglected in planning machinery. If attention is to be obtained, the engine must be such that the engineer will be disposed to attend to it. In one part only it seems impossible to have too much, the boiler. When, however, the requisite provision is made for all things going well and being easily kept right, astonishing results are obtained. Forty days' continuous steaming without a stop is not an uncommon performance. The generation is hardly passed which was told that a steamer could not cross the

Atlantic, and already the engineer has grappled with and overcome the longest distances on the surface of the world.

It is somewhat singular how great a failure the auxiliary steam vessel has been, that is, where the engines are used intermittently, sails being employed whenever the winds are favourable; and this failure is all the more remarkable, because, at first sight, hardly any doubt could be entertained of success. On all long voyages, there are parts of the ocean difficult to cross under sail, and a speed of 6 knots an hour continued even for three days might shorten the voyage by weeks; also, if that speed were attainable, tug-boats would be unnecessary for going up rivers, or entering or leaving harbours, and short cuts might be made available which could not be safely taken under sail alone. Nevertheless, great as these advantages are, and frequently as the experiment has been tried, failure has been the almost invariable result. The famous "Great Britain," the best specimen of this arrangement, has abandoned her long-continued and remarkable service to Australia. The reason does not lie on the surface; it is probably twofold. In these vessels the sailing department cannot be economised, while it is practically impossible to keep the engine expenses in a reasonable proportion to engine services. Hence a slight increase of engine staff enables a continuous service to be maintained, which being done, the sailing department may be at once so immensely diminished as to go a long way towards compensating for the additional fuel; and the vessel changes her character, gaining the advantages and repute of a steamer instead of a sailing vessel.

No review of recent steamboat enterprise and progress would be complete which did not touch on the part Government has played in various ways, whether—

(1) By subsidies for maintenance or assistance of mail services, or

(2) By interference in design, condition, and equipment, on the plea of providing for the public safety.

Both are difficult problems, and if the Author cannot consider that unmixed good has come of the interference, he will not deny that some advantage has resulted, and that political situations have arisen when it was impossible to avoid interference of some kind.

Postal subsidies were originally granted in aid of lines of communication which it was supposed could not live, or at any rate be maintained with regularity, without. No doubt the ends aimed at were realised. Communication was opened at an earlier date, and maintained more regularly, than it would have been without;

and some most imposing fleets have come into existence under the system. But to one who could see behind the scenes as a shipowner, and more especially if he were interested in mechanical progress as an engineer, there was a reverse to the picture. The lines thus created were huge monopolies; the Government money was used to crush competitors, and as a matter of fact, did much to postpone all outside improvement in steam carriage at sea. Also, every result was obtained by simple money expenditure. Science, economy, contrivance, thrift, all went for nothing. The day of subsidies is nearly over; they have caused great waste, weakened the character of steamboat enterprise as a whole, and left those who received them with both fleets and habits unfitted for the race of open competition.

A volume might be written on the results of governmental interference with steamships on the plea of public safety. This interference has grown up, during the last twenty-two years, from a simple survey, principally confined to boats and one or two other similar matters, to a minute and comprehensive inspection, beginning with the laying of the keel, and not ending with the destruction of the vessel. It is attributable to the unreasoning cry, "Any interference is justifiable which provides for safety." The executive department of the Board of Trade has professed itself averse to much of this interference; and it has been the Legislature, more prone to emotion and less informed as to the intricacies of the subject, which has imposed these heavy burdens. In practice, however, the Board cannot be said to have given much effect to its professed aversion, for it has rendered its interference exceedingly onerous and obnoxious, stretching it largely in many directions beyond the points obligatory on it by enactment. The rules on which its legion of surveyors is instructed to proceed have been embodied in a volume, which will repay perusal, and will be found not unamusing. It is an unwholesome fact that, under the plea of safety, the Board is gradually assuming the position of designer; and it is suggested that this Institution would add to the services it has rendered to engineering progress by protesting. The system is too new to have wrought much ill; but resistance to novelties and preference for stereotyped forms are the results only too naturally to be expected.

Did the limits of this Paper admit, it would be interesting to criticise the regulations individually. That they do not approve themselves to well-informed engineers is evidenced by the dissatisfaction and irritation they have produced, and the remonstrances made by important associations. The eccentricity of the laws is

noticeable. Surely life on shore is as worth preserving as life at sea. Yet no law governs the boiler of the railway engine, and the public rides with perfect safety—as years of experience with thousands of instances have proved—behind a locomotive carrying 120 lbs. of steam on a boiler which, if it was in a steamboat, would be restricted by law to about 70 lbs. In fact, if sea rules for boiler strengths were enforced on shore the infliction would be intolerable.

It would be satisfactory, if it were possible, to conclude this review with the statement that, those who have been the actors in this peaceful revolution have profited by it. Shipowning is a pursuit in which, more than any other, success depends on personal management. No doubt a few persons have reaped considerable rewards; but as a whole, and viewed over a series of years, it has been a bad trade for most of those engaged in it. The perpetual progress of invention has made good vessels unprofitable while still new; the ease of competition, except in subsidy-protected trades, the temptation there has been from the advantage every newcomer possesses, and the fitfulness of the demand for steam shipping, have all contributed to produce the result, that the steamship owner has worked for the public rather than his own good. Nor is the case different for the owners of the cargoes his ships have carried. Rapidity of transit has done away with the possibility of large profits, while the necessary hurry and roughness of steamers' ways have much disturbed those accustomed to the accuracy and leisure of sailing vessels. Indeed, it is a matter of frequent remark, that profit and comfort are driven out of any trade a steamboat enters. In fact, the one who almost alone has profited by the change has been the over-idolised idol of these later free-trading days, the consumer.

Mr. STEPHENSON, President, said he had known the Author for many years, and was not acquainted with any man who had more deeply studied or was more conversant with the compound engine. He had not only for a long period engineered his own ships, but had been the consulting engineer and adviser of other large companies.

Mr. HOLT remarked that the changes which had been wrought by steam shipping in a commercial point of view had been enormous. While railway enterprise had been carried out by a few large companies, which had occupied certain districts and rendered themselves very observable, the increase in steamers had been mainly due to private individuals who owned one, two, or three vessels; the great companies which had attracted most attention had probably not moved the greatest amount of cargo, or effected the greatest amount of change.

Mr. SAMUDA, M.P., desired to refer to some points of special interest to the Institution. One was the inspection, or rather direction (as it had grown to be) of the Board of Trade and other departments, which he thought had had a most damaging effect upon the profession. Instead of advancing the science of marine engineering and naval architecture, it tended to prevent the development of the talents of engineers and to subordinate them to those who were placed in absolute authority. He did not desire to find fault with any particular department, but when men of life-long experience were the only ones who really advanced science step by step, by adding improvements in the special matters with which they were concerned, it was disheartening and discouraging to them to find either the Board of Trade, or the Admiralty or Lloyd's surveyors, laying down hard and fast lines, and compelling the registration of their decrees. The result was extremely serious, taking away from the engineering profession the power of development, and causing it to pass into the hands of those who were content in a subservient way to follow the directions of theorists, who insisted on regulating the advance that was to be made in such matters. That might appear to be an ungracious way of putting it, but he spoke as a very old member of the Institution, who had gone through every phase of shipbuilding, and had personally felt the inconvenience to which he alluded. It was a painful thing for men who had acquired a position in their profession, to be dictated to by the representatives of the different departments. He should not have spoken thus if he had not believed that it was in the interest, not only of the Institution but of the public, that a wider permission of development should be

allowed to those who had made the great work of marine engineering their study, and that they should not be interfered with by the departments who undertook to control matters of which they had only a superficial knowledge. He cordially agreed with the Author that the introduction of the screw had immensely advanced steam navigation. In speaking on that subject, he thought there was one name that could not properly be overlooked, the name of the late Mr. Brunel. His works had had the most important influence upon the department of engineering dealt with in the Paper. Mr. Brunel was literally sending his first ship the "Great Western" across the Atlantic, when lectures were being given to the public to prove the impossibility of any vessel reaching America by steam. The "Great Western" was followed by the "Great Britain," and whatever the shortcomings of that vessel might have been, there was in her the very best possible arrangement to make every particle of material of the utmost use in giving strength to the whole structure. With regard to the "Great Eastern"—which was in some respects a most unfortunate undertaking, having, he believed, cost Mr. Brunel his life—it was no doubt far in advance of the times; it had conferred great benefit on steam navigation generally, and had led up to the characteristics and features adopted in vessels of a subsequent type. Where such bold and signal departures from previous methods had been carried out, as those which had been effected by Mr. Brunel in his contribution to steam navigation, they ought to be cordially recognised. With regard to the alleged success of American wooden steamers used with a screw, he thought it was a fallacy to suppose that wooden steamers could achieve any amount of success as compared with iron steamers. A wooden steamer might be made with great advantage to be worked with paddles; but when an attempt was made to drive the power through the stern, where every fastening put in the vessel by being agitated was a continual source of destruction by enlarging the hole and diminishing the size of the fastenings, the state of things was very different from that existing in an iron vessel, which was practically a homogeneous sheet of iron. If it were not so, the latter would not stand as it did twenty years' continual rack brought upon it by the whole of the power being passed through the stern. His statement might be confirmed by what took place in the early period of screw navigation. The Government were then the only persons who used very large power through screws, but it was found so incompatible with the existence of the vessels, that it became a question of giving

them up altogether or of substituting iron vessels; and iron vessels had fully realised all the expectations formed of them, there being no longer any fear of the difficulty of passing power through the stern. With regard to the question of subsidies, he could not quite accept the view expressed in the Paper. He thought Government had done right in giving large subsidies to steamers. If they had not thus encouraged the development of steam navigation, shipbuilders could not have produced the kind of steamer that they were now enabled to construct. It was quite true, as the Author had stated, that since an opportunity had been afforded of watching what had been accomplished by subsidised lines, other steamers had been brought into competition with them, so that they would be placed at a considerable disadvantage when the subsidies had run out, since the other steamers would be able to take their place and do the same work on cheaper terms. Vessels, which would work at a profit aided by a subsidy, might be left stranded when thrown upon their own resources. The public, however, had had the full benefit of the system; they had had the advantage of steamers of enormous size and of a speed that never would have been dreamed of at so early a period. He believed that steam navigation was now far ahead of what it would have been but for the subsidies that had encouraged it.

Mr. E. Reynolds did not know whether it would be possible in the discussion to keep as clear of detail as the Author had done, because his own specialities were matters of detail to a very large extent. The Author had advocated the single engine, and had used it with great success. That was a matter of some consequence in regard to the advance of navigation, because if those engines were cheaper or more economical in working, they took up less room, and ought to be adopted. But it did not appear to him that they were the most economical arrangement, because a single engine must apply the power to a yielding medium like water by fits and starts; it must be at one portion of the revolution a force acting upon the water one-third greater than the average force, and at another part of the revolution the propeller must really be propelled by the water. It was therefore difficult to imagine that it could be the most economical arrangement; and he was strongly inclined to think that in practice it had not proved itself to be so. In his indirect connection with marine engineering he had made several screw propellers for American steamboats, and in all those cases the blades were unequally placed, two near together and the others wider apart, so that the

Americans recognised the difference of effort of the engine, and he believed that the Author had practically recognised the same evil by introducing a tolerably heavy fly-wheel. Of course the fly-wheel was not a complication, but it was ineffective weight, and it remained to be seen whether with the same total weight greater efficiency could not be secured by two engines. From the reference to the construction of the engines of the White Star ships it would appear that the Author recognised that it was partly a question of size and convenience. It was possible that the introduction of the single engine in the United States might have been to a large extent a matter of economy, in consequence of the rather crude construction to which the Americans had been driven by the excessive dearness of labour and the great cost of iron. That state of things had since been altered, and so, he believed, had been their practice in marine engineering. The designer of the engines of one of the largest lines of American steamboats had recently shown him his drawings for those engines. In some of them the English plan of two cylinders had been adopted, and in others there were four cylinders with four cranks. On the whole, it appeared to be a matter of expediency with reference to the particular circumstances. With regard to indicator diagrams, to which the Author had alluded, they were, no doubt, too much relied upon by a large number of engineers. It was possible to get almost any results from an indicator diagram; but the sole question for shipbuilders was how far a ship could be driven, and at what speed, by a certain consumption of coal. With reference to the White Star fleet, to which allusion had been made in the Paper, the first two ships were built with the intention of working with a moderate rate of expansion. They had engines with ten boilers containing twenty furnaces. One of those ships was now in existence, and she was notoriously a good one, except that she was short of steam. The actual speed of those vessels (as shown in the Blue Book on the loss of the "Atlantic") had been about 12 knots. In the next four ships with similar engines there were two additional boilers with four furnaces, in all twenty-four; and there had been an actual increase of speed almost in the direct ratio of the increased number of furnaces. That went to show that a good indicator diagram made out by a large measure of expansion was not all that was wanted. In the last two ships one-sixth had been added to the cylinder capacity and one-third to the boiler capacity, with the result that one-third more tonnage was propelled not merely at the same speed as before, but at an increased speed of 1½ knot an hour, the latter being of itself

sufficient to account for the increase of fuel. He had no doubt that by enlarging the capacity of the cylinders of those ships better indicator diagrams could be obtained, or rather a larger amount of power could be shown upon the indicator cards by a higher measure of expansion; but he thought the performance of the ships would be materially worse. The Author had joined in the general condemnation of the interference of the Board of Trade, which was, no doubt, annoying to the enterprising and highly instructed persons who managed the most important steam trade of the world. But that was not the whole steam trade of the world; and it was impossible for the public to forget that at the time when the interference became serious they were accustomed to hear of iron ships breaking their backs at sea without warning; of such cases as that of the "London," a well-found ship, but probably overloaded, and too deep in the water for her length, lost in the Bay of Biscay, with an enormous sacrifice of life, a large portion of the crew, however, escaping in open boats. Such being the case, it was impossible to say that some supervision was not necessary; but it would be desirable that such supervision should extend more to essentials and less to details. One point to which he desired to direct attention was that some of the best class of engine-men were kept out because they did not pass a Board of Trade examination. He had no hesitation in saying that if a similar examination were required of railway engine-drivers accidents would be increased tenfold. It was as if, in engaging a turner, he should examine him as to his capability for designing a lathe, and not as to his power to make the best use of the tool before him. Another question was the substitution of steel for iron in steamships, as to which it was important to lay down good rules, but he feared that the Board of Trade would fall into the same error as other bodies had done in devising rules for the use of that material. The English Government appeared to have adopted rules taken from those of the French Government; and he saw with regret that Lloyd's had adopted similar ones. The material was to be tested by subjecting strips sheared from every plate to tensile strain, and also by cold bending to ascertain the capability of flexure without cracking (which was right enough); but they were further tested—not, as might be expected, as to the amount of indentation which a riveted seam would bear without splitting at the holes, or anything of that sort—but by heating strips red-hot, dipping them in cold water, and afterwards doubling them up. Now, surely, if there was one risk to which a ship's bottom was less liable than another it was that of getting red-

hot. Such a test could only prove the softness of the material, and that it was not of the highest strength that might with propriety be used for the purpose.

Mr. MERRIFIELD agreed with the Author in what he had stated with regard to the length of ships. As he had said, the middle part was that which carried and paid, and consequently there was a natural tendency to lengthen it. He also agreed with him that a decided limit was placed on the possibility of lengthening ships by any restriction on their size, and that for distant and rough voyages, like those across the Atlantic, it would be impossible to have with any degree of safety long ships of small size. He supposed also that there was a practical limit to the size of ships in the ports they had to serve. That was emphatically the case in the Channel passage, for it was entirely owing to the restriction on the size of the ships imposed by the ports that the service was so bad as compared with that which might be established with better ports and better ships. There was also a sharp commercial limit imposed in most trades to the size of the ships by the amount of cargo they could take in at a particular time at a particular port; he doubted, however, if that restriction applied to some of the great lines of steamers, such as those on the Atlantic ferry (so to call it) between Liverpool and New York; and it would not surprise him if at no distant period vessels as large as the "Great Eastern" crossed the Atlantic in considerable numbers. With regard to indicator diagrams, there could be no doubt that they recorded the pressure in the cylinder, and absolutely nothing else, telling nothing of what took place in the boiler or in the fire. In many cases where the application of the engine was almost direct, and where the loss of efficiency in the engine was well known, as in the Cornish pumping engine, the indicator might be to some extent a guide to the work actually done; but in the screw propeller that was very far from being the case, for the work done in the engine by no means represented the work done in driving the ship. The screw was not only an indirect propeller, but it was primarily a reaction propeller; it did not push against a rigid substance, but drove the ship by the stream of water thrown back. By virtue of the principle that action is equal to reaction, the natural tendency of things in those circumstances was that the action and reaction should tend to equality; consequently, although it was possible to do a great deal better than that, and by means of various artifices to make a propeller that did not throw away anything like half its power in the reaction, still the tendency was

that way, and the loss was great; the indicator, therefore, was no guide to the power actually employed in driving the vessel. He was not sure that he had rightly understood the Author's reasoning in one respect, but he thought he did not attach quite enough importance to the difference of pressure in engines—to working with as high a pressure in the engine as possible, and getting as absolute an economy of coal as possible. It was, of course, well known that the efficiency of an engine was theoretically limited by the ratio between the difference of temperature of the incoming and outgoing steam, and the absolute temperature of the incoming steam. Practically one temperature was fixed by that of the stoke-hole; the other, however, was to a great extent within control, and he had more hope of getting great economy from that source than from almost any other; and he valued economy rather more highly than the Author seemed to do in respect to ocean-going ships. It was true there were certain services where the amount of coal consumed bore no very large proportion to the other expenses; just as in some luxurious households the cost of bread and other necessaries of life formed but a small portion of the expenditure, so that it was immaterial to them whether bread was cheap or dear. That, however, was not the case with the public, nor was it the case generally with steam vessels, especially in long steam lines. Those, he thought, were still working very near the limits imposed upon them by the absolute economy of coal. Every pound of coal economised on those lines enabled them to drive the ships so much farther with advantage, and he believed that for the present, and at least in the immediate future, any great improvement in steam navigation was likely to be in that direction. With regard to the question of the interference of the Board of Trade, he considered it as only one small branch of a very great change that was taking place in English administrative history. Forty years ago the only ideas of Government in the country were confined to keeping the Queen's peace and raising the revenue. The only example of administrative interference was the Post Office. In 1834 the Local Government Board was established, and since then one department after another had been formed to take charge of large portions of public business which had been usually left to those who were individually concerned in working them, such as education, sewage, and other sanitary matters. Meanwhile the Civil Service estimates had increased from two millions to thirteen or fourteen millions, without counting the revenue departments, and that increase meant the actual interference of the Government with the life

and business of society. No doubt there were many inconveniences from the system adopted, but the public must now look rather to their mitigation than to any prospect of getting rid of them. England having become a crowded and wealthy nation, every one of whose members was regarded as of national importance, and it having become more and more necessary and usual to protect individuals against every species of eventuality, the public must now expect that interference to be maintained and to become more and more minute; circumstances having forced them to give up a great part of their individual liberty. No one regretted this loss of liberty more than himself. He had no doubt, however, that, in the case of merchant shipping in particular, the evil had been much aggravated by what had been forced upon the Board of Trade, namely, sentimental legislation. The Board had resisted it as long as they could—for no persons were better able than the civil servants to foresee the evil of this centralization of detail, not only to the public inconvenience, but to their own personal burthen, more especially by the enormous amount of work and responsibility forced upon them by increased centralisation and meddling with detail. At the same time, he thought that the public, and the Institution of Civil Engineers in particular, would do right to struggle for all the liberty they could get, especially the liberty of improvement, and to do their best to prevent the Board of Trade from dictating to them in matters of detail and design. The Board of Trade were not quite their own masters in the matter. When they appointed an officer to inspect a vessel, and made him practically responsible for seeing that it was safe, and insisted upon his enforcing that responsibility on the owner, there was an inevitable tendency on the part both of the owner and inspector to insist upon what they knew to be safe, and not trust to chance or skill to keep them safe—to say, "I know this invention is safe; why bother me with anything new and risky?" While such a tendency should be as far as possible checked, the Board of Trade could hardly be blamed for it, and still less its permanent officers.

Mr. C. LAMPORT observed that Mr. Merrifield might have gone farther in his observations as to the steam indicator; for not only did it tell nothing of what went on in the boiler or in the fire, but it told nothing of what went on in the engine driven by the steam; for it gave no indication as to the workmanship or the combination of parts. That was a serious defect. Something further was wanting, and he wondered that the Institution had done nothing to determine what constituted a real HP. Agri-

culturists, who were supposed to be a stolid and torpid class, had been the first to apply to their engines a test at once practical and scientific. They measured the exact work done by a brake, and the amount of heat that was lost by applying a pyrometer to the chimney. It would be impossible to ascertain the amount of heat generated and wasted until the amount thrown from the chimney was measured in relation to the coal consumed. It was not often that he had heard anything said by Mr. Samuda with which he could not agree; but now that that gentleman had gone out of the track with which he was so familiar, and had touched upon the politico-economical bearings of the question, he had listened to him with unmitigated astonishment. That he of all men, so enterprising and scientific, should advocate anything like a Government subsidy for the promotion of scientific or industrial progress was a problem, the solution of which he had yet to discover. To depend upon Government subsidies for the progress of steam navigation was to go back to the old principles of protection. But he could not believe that Government had ever volunteered to pay money for such a purpose. The fact was that they wanted a piece of work done, and, in a true commercial spirit, they were willing to pay for it. He wished to say a few words as to the dealing which the question of ocean steam navigation had met with at the hands of civil engineers. Within the last two months he had had the pleasure of listening to two Papers on the subject. That of the Author was most interesting and important, and had been brought forward at an opportune moment. The other paper was by Mr. Rennie at a meeting of the Institution of Naval Architects at Glasgow. Both Papers, however, dealt exclusively with the past, giving no indication of what the future might be; and he (whose capital was involved in the success of that branch of national industry) was still in the dark on that part of the subject. The Author had referred to the substitution of iron for wood, and pointed out that ships traversing the ocean under steam power could be increased in length, and that consequently the water resistance was much diminished. He thought that the conclusion was right, but that the reasons were not entirely correct. The alteration of the length had been coincident with, rather than consequent upon, the introduction of iron; and he believed the cause would be found in the fact that the introduction of steam had led to the disuse of sails. So long as ships were exclusively, or in a great measure, navigated by the pressure of wind upon a large area of sail surface, stability was a necessary element; but when the chief propelling power was de-

rived from a screw inserted within the body of the ship itself, that element of stability was no longer so necessary or important a one, and the result was that naval architects were free to follow the bent of their scientific induction, and substitute a greater length in place of a greater breadth. The law of stability was as the square of the breadth; therefore, if a vessel was to be propelled by sails, it was absolutely necessary that she should have, for a given displacement of water, a considerable lateral power of resisting the influence of the sails. He thought that in such an institution shipowners and shipbuilders might have expected to hear something as to the possible substitution of Landore steel for ordinary iron. He believed that a complete revolution as to the use of material was impending. Government had taken the question up, and had begun to use that admirable material in substitution for iron; and when shipowners had overcome the hesitation always attending the introduction of a new material, he believed they would largely substitute steel, which had a tenacity of 50 tons in comparison with iron, which might be measured at from 19 to 22 tons. Lloyd's had already taken steps in the matter, and he believed that that body, although very cautious, did not shut its eyes to all improvements, but was willing to yield to any arguments which could be urged in their favour, so far as they had a practical bearing. The object of Lloyd's was to protect underwriters whose business depended upon the safety of ships, and had nothing to do with shipowners' profits. To sum up his views in a few words: he held the propeller which, as the Author had properly stated, had initiated a revolution in steam navigation, to be a most imperfect instrument, because, from the nature of the composition of forces, it lost half the power applied by the engine. In the second place, he thought that iron should be substituted for steel. In the third place, even the compound engine could not be said to have attained anything like perfection, since it was generally acknowledged that not more than four-elevenths of the heat generated was utilised, and Mr. Scott Russell had stated that the amount did not exceed one-tenth. Were engineers to rest contented with such results—imperfect steam power, something inferior to the best material, and a bad propeller—to carry on the commerce of the world? If so, he had underestimated the suggestive skill of civil engineers, and underrated the desire for progress on the part of shipowners, and the power of shipbuilders to carry out whatever might be necessary to secure the most satisfactory result.

Mr. Scott Russell remarked that the Author had dealt with the question of what progress had been made during the last

twenty-five years in the machinery of ships, in the construction of ships, and in their commercial use and application to the earning of money. He had stated that during that period the British carriage of goods had passed from sailing ships to steamers, and that the iron ship had taken the place of the wooden one. Those were two axioms to which no one would offer the slightest objection, but that was, in fact, all that the Author had said on the very important question. In propulsion the Author simply stated that the screw had taken the place of the paddle-wheel, adding that that was nothing new, for the screw had been used before. As engineers, however, the Author said they had done much: they had introduced the compound engine, and that was a great triumph of machinery. No doubt Mr. Elder had done a great deal by the introduction of the compound engine. As the Author had said, it had been used a very long time without being highly appreciated, and for what reason? Simply because he had used it in the Pacific, where coal was dear, and economy of fuel was of great importance. Here it was not so highly esteemed, because fuel was plentiful. He remembered on one occasion saying to a gentleman, "Why do you not economise your fuel a little?" and his reply was, "The fuel costs so little that I do not care so long as one man is enough to put it in. If I required two men to put it in, I should have to economise." The Author went on to say, that even in regard to the compound engine there was no novelty and no invention. That was true, because the use of steam in two cylinders had been invented before. There was one omission in the Paper to which reference ought to be made. In his opinion the creation of the line of the Holyhead packets had been one of the most distinguished triumphs of naval architecture and mechanical engineering during the last twenty-five years. Those boats were marvellous for their speed, for their seagoing qualities, and for the admirable structure of their engines. He had had nothing to do with building them, but he had the greatest respect for all those who had had to do with the creation of that marvellous fleet, which he believed had no rival. He agreed with the Author in thinking that auxiliary engines had been a complete failure, and he was very glad that the subject had been brought forward, because it might have the effect of preventing any of those terrible losses which occurred from attempting to introduce steam and sailing together, the one to the loss of the other. The Author's remarks with regard to shipowners were very instructive and characteristic. A few shipowners, he said, had succeeded in getting a great deal of money, but for most of them trade had been

had. Shipowners, it appeared, had worked for the public good, and not for their own. Then owners of cargoes had also suffered. Again, it appeared that whenever steamships were employed, hurry and roughness disturbed the business of the shipowner and the cargo-owner, and drove comfort out of trade. Profit and comfort had thus been driven away, and therefore, he supposed, steamships should no longer be built. The Author had stated that "the consumer, the over-idolised idol of free trade, has alone profited by steamships for the last twenty-five years," and that was "the conclusion of the whole matter." He had looked anxiously through the Paper to get the best possible instruction as to what shipowners and shipbuilders should do in future to benefit the shipowner and put money into his pocket. He was obliged to say that builders had often thought more of the pocket of the shipowner for whom they were building, than of the over-idolised public with whom personally they did not come into contact. He agreed with the Author that shipowning success depended on personal management. If shipowners were better educated, knew more of engines and boilers, could better distinguish between a good and a bad ship, and between good and bad shipbuilders, they would make more money, a little more slowly perhaps, but much more surely in the end. Much depended not only on personal management, but on personal character. When shipowners went to shipbuilders and engine-builders of known and reliable character, they always got good ships, but if they went to the last newcomer who had no character, they very often had bad ships, and then the blame was laid, not on the shipowner, but on the builders of the ships and engines. He believed that the greatest failures had arisen from the ignorance, incompetence, and cupidity of the shipowner himself. He had seen large fortunes made by shipowners, and they were men who first of al put their ships into a trade which they had already proved to be a thoroughly good, honest, and profitable one. They then went to men of the highest character to get their ships and engines made. Instead of going from one to another to get the cheapest possible ship, they kept to the old shipbuilder and engineer, on whose work they could rely. First, they would put on the trade a ship to earn a high character, and when that was done they built a second ship of a higher character, profiting by the experience of the former. They next built another which raised their character still higher, and their profits too. Then, instead of insuring their ships with insurance companies, after they had built a sufficient number they never insured at all, and

as they never lost they saved all the insurance money. Finally, having built a ship with a good character, they sold it to people of less character, who paid a large sum in addition to the value of the ship, in order to buy the character of the ship and the owner along with it. With the money thus obtained they built a newer and better one than before, and so they went on, always increasing in the excellence of their ships, always keeping to the same engineer and the same shipbuilder, always sailing their ships with the same high character, and building other and better ones for themselves. Many of the largest fortunes in the country had been earned in that way, and he would ask the members if they were not proud of such shipowners and such ships. He quite agreed with the Author that shipowners should select engines for simplicity, accessibility, and ease of repair, and should avoid engines with too many parts, and with too few parts. No better principles could be laid down for the construction of modern engines, but difficulties now and then came in the way, and one was what was called the personal difficulty. Good engines required not only an intelligent ship owner to manage them, but superior engineers to tend them. Many ships of an inferior character, with able and well-paid engineers, had done better work than was done by less intelligent owners of better ships, who screwed down the poor engineer to the lowest possible sum. He once took an old steamship and a certain amount of money in exchange for a good new steamship. He selected for her the best captain he knew, and gave him double the salary he had before, and also the best engineer he knew, giving him double the usual salary. The owners of the new ship wanted a cheap engineer and a cheap captain, and they got both. Both ships went into the same service and worked in it for two years. The old ship with the good engineer and captain earned a profit of £20,000, the good new ship with the new capain and engineer earned in the same time a loss of £15,000. With regard to the introduction of compound engines, half the amount of fuel had been saved, and that was certainly a very great step. Whereas the former engine consumed 4 lbs. per indicated HP., the compound engine consumed only 2 lbs. But although that was the case, the Author stated that compound engines were now being built of a bad character, with a very short stroke and chese-shaped cylinders, whatever that might mean. The view of the Author evidently was that the engines should make a long stroke, and that there should be a deliberate movement of parts, also that there should be valves with great range of expansion. He agreed with the Author in every one of those points. The first and second,

however, according to the Author, were not to be obtained, and valves with a good rate of expansion were inadmissible in a screw steamer. What, then, was to be done? He was afraid it would be necessary to go back to the cheese-shaped cylinders. The Author stated that the Americans had beaten the British; and his reason for saying so was, that long cylinders and long strokes could not be obtained, in consequence of the present form of engine in screw steamers. He had seen, however, in the hands of some of the best marine engineers, methods of arranging the engine which would allow a screw steamer any length of stroke desired. No doubt a long stroke was the thing wanted in a marine engine; but accompanying it there should be a higher velocity of piston (otherwise the screw would go slower), a higher degree of expansion, and a higher pressure of steam. Low-pressure boilers ought at once to be abandoned for high-pressure boilers; and boilers should be made which would not prime. With regard to the screw, it was not always wisely placed. It would be found that there was in the stern of a ship one point where, if the screw were placed, the maximum resistance would be obtained. That point was where the stern wave just culminated and went down again. In every ship that wave, with the vessel at full speed, was at a particular point—a little farther back, he thought, than the screw was frequently put. The Author appeared to think that Government subvention had been injurious to ship and cargo-owners. He was afraid that the Author had not had a Government subvention. He thought, however, that subventions for mail ships were a great benefit to the public and to the nation. What he himself desired to see was that a great number of ships should be built fit to do special service in time of war; that in time of peace they should be subventioned, and made to carry mails; and then in time of war the Government, instead of having to build a large number of ships at a high price and in a great hurry, would have a considerable fleet at their disposal.

Mr. FLANNERY thought the Paper a very important one, as dealing with a wide subject, and expressing the opinions of a gentleman of high reputation as a marine engineer; but he thought that, if the Author had given some of the reasons on which he had founded his theories, members who came to learn would have learned even more. With regard to compound engines, the Author appeared to admire greatly the design and boldness of the Americans, and thought the single-cylinder engine might be more economical and suitable for general purposes than those in which expansion was conducted in two cylinders; but he had

shortly afterwards expressed an opinion that higher pressures must eventually take the place of those at present in use. There seemed to be a difficulty in reconciling those two statements. The chief reasons for adopting two cylinders were that the impact could be reduced at the beginning of the stroke by having a small piston with a high pressure, and a large piston with a low pressure per square inch; and that the range of temperature could be reduced through which any single cylinder passed, by admitting high-temperature steam into one cylinder, and a lower temperature steam into another. These reasons were undoubtedly increased, in a large degree, if the pressure and the temperature of the steam were increased; and if engineers were driven to the use, for general purposes, of two cylinders for the present pressure, how much more would they be driven to the use of three or four cylinders for very much higher pressure? With regard to the single-crank engine, the Author had found no difficulty in dealing with it. Any one who went into the engine-room of a steamship fitted with a two-cylinder engine and two cranks, was struck by the fact that a large amount of space above the engine was apparently wasted, having no other use than that of ventilation. The Author, he believed, was the first engineer and shipowner who attempted to reduce that disadvantage. By the engine with two cylinders placed vertically one above the other, and working with a single crank, he had reduced the amount of space necessary for a given HP., and had also, he believed, reduced the weight of the engine to a slight extent, at the same time increasing the cargo-carrying capacity of the ship. At one place with which he was acquainted in the North of England that method was coming more and more into use. He had called attention to the matter; hoping that the Author would be able to say something as to the amount of gain secured by the use of those engines. With reference to the indicator, in face of the facts that the Admiralty had entirely abolished the term "nominal HP." and purchased the whole of their machinery for the Royal Navy upon the criterion of indicated HP., together with the specification of proportions, and that Lloyd's Committee had issued a circular to the chief marine engineers of the kingdom, asking their opinion upon the question of nominal HP. and the mode of calculating it, because they found that a great many shipowners overrated or underrated, according to their commercial requirements, the nominal HP. of their ships, it was startling to find the Author saying that indicated HP. was a criterion of no value in the purchase or comparison of engines. He ventured to think that if, with the

indicated HP., there was a strict specification of proportions and sizes of parts, that would afford a very excellent comparison between engines of different powers and different types. There was one important remark in the Paper with reference to boilers. About four years ago the late Mr. Ward Hunt aroused the deepest consternation as to the state of the boilers in the Royal Navy, which he said were decaying rapidly. It was, he believed, an admitted fact that the lives of boilers with modern compound engines and surface condensers in the Royal Navy had been much shorter than the lives of those of the old low-pressure type. In contrast with that the Author, a gentleman of great experience, had come forward and stated that the boilers in the mercantile marine lasted as long now as ever. He hoped he would be able to state why there was such a marked contrast in the two cases. A comparison had been made by him between marine and locomotive boilers. He stated that a boiler of the locomotive type would be allowed to carry passengers working at a pressure of 120 lbs., but that, if the same boiler were on board ship, 70 lbs. pressure would be the utmost allowed by the Board of Trade. Taking into consideration the surrounding circumstances, the contrast was not a violent one. The boilers of a ship were sometimes under steam for forty or forty-five days; but a locomotive boiler, after being under steam for seven or eight hours, was sent into the shed and inspected. Again, the chief engineer on board a sea-going ship did not, as a rule, possess the same attainments as a superior officer of the locomotive department of a railway. He was aware that the examiner-in-chief of engineers was doing his utmost to increase the technical knowledge of sea-going engineers, but notwithstanding all his efforts, the scientific attainments of those men were not great. Locomotive boilers, moreover, with regard to the generation of steam, were much more under control than marine boilers. In shutting off steam from a locomotive engine the blast was stopped, and the generation of steam was practically stopped, or at all events reduced to a large extent; but there were no such means of reducing the generation of steam in a marine boiler. He could not conclude without paying a tribute of respectful admiration to the manner in which the Paper had been written. It did not contain a single allusion to the way in which the Author himself had contributed to the progress to which he had referred. Knowing the value of his contributions, not only as an engineer, but as a shipowner, the meeting could not but feel that he had acted both modestly and wisely in not referring to the matter at all in his Paper.

Mr. T. GRAY observed that the Paper raised questions of the greatest importance to commerce, and therefore of vital interest to the chief commercial country in the world. The Author himself had played no unworthy part in contributing to that greatness, and his own fleet of steamers—should he say in consequence or in spite of the interference he condemned?—now floated as one of the nation's proudest evidences. No one was more competent than the Author to fulfil the duty that he had imposed on himself. He quite concurred in the remarks of Mr. Flannery with regard to the extreme modesty of the Author, who had prepared for the archives of the Institution a statement which would be referred to centuries hence, when what was now too near to be appreciated at its full value would have passed into history. The Author had given prominence to the name of Elder, and thus paid a tribute to the memory of one whom all acknowledged as the greatest leader in a most remarkable reformation of the steam-engine. He did not propose to follow the Author through his Paper, but would confine his observations to two of its features: first, that which had cast doubt upon the wisdom of State interference with the concerns of daily life; and, secondly, that in which the Author prayed the Council of the Institution to use its powers of intercession between the Board of Trade and that part of the British public whose business or pleasure compelled them to "go down to the sea in ships." He was entirely at one with the Author in his views concerning the unwisdom of interference with the details of the construction and equipment of ships—especially when, as in the present case, that interference lessened, and perhaps destroyed *in toto* the responsibility which ought to rest on the shipowner. He did not think that the way to insure safety was to remove responsibility from any one, but that the very reverse of that method should be adopted. The question resolved itself into this, not only with regard to ships but with regard to all industrial occupations: Was the State to become mother and nurse and keep industry in swaddling clothes, or was it to be chief policeman and to punish evil-doers? Twelve years ago he had expressed his views on the subject in a Paper read at the Society of Arts, and those views then and subsequently expressed had led the Author to assume that regulations, which were framed solely with a view of carrying into effect a trust imposed on the Board of Trade by the nation, were framed with the unworthy and ridiculous motive of proving the exceeding irkfulness of inspection. He hoped that the Author would, on reflection, give the framers of the rules credit at least for honesty. The observation he had made on that point

was the only unkind act he had known him commit. He knew no one inside or outside the Board of Trade who did not regard the excessive details with disfavour. He was at one with the Author in his wishes. He took his place in the same boat with him, and trusted that, by pulling together, they would come to some common understanding. He wished to remark, that the legislature by express enactment required the Board of Trade to certify that boilers of steamships were safe for twelve months, and to fix the working pressure: and that the instructions of the Board as to the strength of boilers were founded on the teaching of the late Sir William Fairbairn and Professor Rankine. It was not the Board of Trade that was attacked when it was stated that boilers should not have the factors of safety of 8 and 6: it was those professors and their disciples. They had been taught that boilers ought to have factors of safety of 8 and 6; and if the Institution and the Author, or any competent authority would tell the Board of Trade and the nation that the teaching of Fairbairn and Rankine was wrong, and that those factors were no longer necessary, he had no doubt that the Board of Trade would be able to alter their instructions.

Mr. THORNYCROFT desired to make a few remarks on the comparison of single engines with engines having more than one crank. When two cylinders were placed one above the other, they were, for his purpose, single engines. The Author had laid stress on the value of single engines, but had not shown in what their economy consisted. As a shipowner he was not interested in the indicated HP. of engines, but in how far the engines would propel the ship with a certain amount of coal. Mr. Thornycroft believed that Mr. Froude was now bringing out a dynamometer by means of which the work done in the screw shaft might be accurately estimated; and when it became the custom to measure the power of the engines by the work actually available in the screw shaft, it was probable that the Author's estimate of the value of indicator diagrams might be more general. He did not think that the Author intended to discourage the use of the indicator; but he understood him to refer to short-stroke engines having great weight on the journals. When there was a pair of engines, the crank shaft being somewhat flexible compared with the frame, the forward engine not only exerted a pressure on the journals of its own bearings, but, by the twisting of the after crank pins, a great strain was also thrown sideways on the after journals, and it has been shown that the amount of power delivered to modern war ships was only a small percentage of the work done by the steam

in the cylinders. In the American paddle-steamers the hulls were too shallow to be of favourable form for easy or economical propulsion, so the engines must give a high duty in work done on the ships to give the favourable results stated by the Author. He considered that the small crank pin, single engine and valve gear working with a very small friction, might be taken as contributing greatly to the high efficiency. His object in rising had been to direct attention to the important bearing Mr. Froude's dynamometer had on the subject of the Paper, and to express his conviction of the great value of so perfect an instrument for measuring the available power for propelling a ship.

Mr. T. W. TRAILL said the remarks in the Paper, as to boiler purposes, were of such a nature that it was to be regretted that more facts and less general imaginative ideas had not been stated. This would have been fairer to all parties, as the objections could then have been answered, and every one would probably have been more benefited by the discussion which would have arisen. Engineers had frequently lofty flights of imagination. Their grand ideas might take various forms and might be instructive and useful, and it would seem desirable that this should be so; but although these ideas might be novel, unless they could be established by facts, they would probably not do much to reward their Author or benefit those interested in engineering matters, and this, irrespective of whether or not the interest of the Author arose from a love of his profession, or from the fact that he was in a pecuniary way connected with engineering, or what was of more consequence, be the means of saving life. He would then merely state a few facts, as such were without doubt what in the present case would seem to be desirable, and he could only remark, that if the pressures alluded to by the Author were obtained by anything like the method which he had on a former occasion advocated in print, that the most recent experiments on the bursting strength of actual boilers most clearly showed that the real strength of the boiler was not that which would be attained by adopting the ideas of the Author, so far as Mr. Traill was in possession of them. The two cases which he should allude to were circular boilers, one of them 11 feet 6 inches in diameter, in which the percentage of material left in the plate was 56, and thickness of plate at fracture $\frac{11}{16}$ inch; and one of 11 feet 3 inches in diameter, in which the percentage of materials left in the plate was 53, and thickness of plate at fracture $\frac{3}{4}$ inch. As they both went by the plate giving way he would not enter into any more details. The first actually burst at a pressure of 195 lbs., the second at 230 lbs.

Now he would ask the Author if he would state the factor of safety he would adopt, and whether he still admitted that it might be taken as a postulate that six was a proper factor for a boiler, as the boilers in the cases Mr. Traill had given, would, by the Author's ideas, have had factors of safety of about 5·9 and 7·1 respectively, whereas the real factors of safety were 3·9 and 3·8 respectively. In one case the boiler burst within $\frac{7}{10}$ lb., and in the outer case $\frac{3}{10}$ lb., of what the calculation by book showed they ought to have burst, and however much the Author might object to the method, he maintained, that up to that time there was not a more correct one. Adopting the plan advocated by the Author in a Paper issued some time since, it would be found that, in the first case, the calculating bursting pressure would be about 298 lbs., or 52 per cent. above the actual bursting pressure, and in the second case it would be about 426 lbs. or 85 per cent. above the actual bursting pressure. Further comment on such a method would be unnecessary. The apparent discrepancies in the two cases arose from the fallacy in the method advocated by the Author. He could state more facts, but the figures which he had given most clearly proved that the principles laid down in the book which was found to be not unamusing were based on facts and not on fiction, and in dealing with steam, engineers were not, he held, justified in dealing with anything but facts.

Mr. D. Mac Iver, M.P., said that for many years he had been interested in shipping as a steamship owner, and he took pride in steamships, not merely for what they made in the way of profit, but in a mechanical point of view. The Paper in all its essentials deserved the approval of those who had had an extensive experience of steam shipping, but there were a few points in it on which he differed from the Author, and some other points which he thought were not quite so exhaustive as the Author apparently intended them to be. He had no desire to defend the Board of Trade in everything; he knew that they were not always right, but he thought that on the subject of boilers the Author was still further wrong. He would ask what had been the result in those vessels in which the Board of Trade standard of efficiency had been departed from? He wished to mention the case of four vessels, two of which belonged to personal friends of his; in the third he was himself at one time a part owner; the fourth was a tug, whose owner he did not know. Three of those vessels had Board of Trade certificates, and as long as they possessed them they went safe; but a time came when, according to the Merchant Shipping Act of 1876, vessels were allowed to carry twelve pas-

sengers without that certificate, and when the people who had the management of those vessels thought they might disregard the Board of Trade conditions in reference to boiler pressure. In each case there was an explosion, with serious loss of life. The conditions under which locomotive and marine boilers worked were (as had been pointed out) very different. The marine boiler went away for a long time; ships did not carry too many engineers; and, owing to sickness or other causes, a boiler might be in charge of less competent hands than the owner intended. He thought that the margin of safety should be larger at sea than on shore. His principal object in rising was to ask for the support of the Institution of Civil Engineers with reference to matters of legislation. In the House of Commons there were very few persons who had any practical acquaintance with the management of steam shipping. On the Conservative side he was absolutely the only steam shipowner, other than limited liability proprietors, and those on the Liberal side could be counted on the fingers of one hand. He thought that recent legislation, however well intended, had really proceeded very much in the direction illustrated by Mr. Gray's speech. The Board of Trade, it was quite evident, entirely failed to realise how far they might usefully supervise matters connected with shipping; and, without having any intention of doing so, they seriously troubled, harassed, and annoyed the shipowners of the kingdom. They left undone many things which they ought to do, and busied themselves in matters which would be better let alone. The duties of the department had far outgrown the machinery which had those duties to perform. The Board of Trade attempted far too much, and there was not sufficient separation between the executive duties connected with shipping and those connected with railways. Shortly before the close of last Session he had given notice of his intention to ask the House of Commons as early as possible to consider whether they should not appoint a select committee to inquire into the duties of the Board of Trade, and into the operation of recent statutes. If that view had the support of gentlemen present, he thought that they should do something to shape public opinion outside. A few steamship owners in the House of Commons could not do much unless they were known to be backed up by a strong outside feeling. He desired to speak with the greatest respect for Sir Charles Adderley and Mr. Stanhope, but yet one could not help remembering that those gentlemen came into their present positions without any special training in regard to the practical details connected with shipping, railways, or machinery, and that

they inherited the mischievous Board of Trade policy made for them by hon. gentlemen on the other side of the House. Whether under the present or the late Government, he thought that the Board of Trade, as a public department, had distinctly "gone off the rails." To a great extent it had driven trade out of the country. It was not possible that all the carrying trade could be done by first-class ships. Second-rate sailing vessels were really necessary to the country's prosperity, and had been displaced to make room for foreign shipping; and that which was true of sailing vessels was becoming more and more true every day of steamers. There was not the slightest reason why it should be so. It was not so much new laws that were wanted as a reorganised Board of Trade; and there would be no great difficulty in procuring that if it were asked for strongly by the public. The present position of matters was this. There was no reasonable supervision, including alike the British shipowner and his foreign competitor, but the British shipowner—and he alone—was overwhelmed with useless annoyances; and the Board of Trade capped these with their theory that disasters were to be prevented by threats of punishment. In regard to the prevention of disasters by punishment for alleged misdemeanour, the shipowner who understood his business and gave personal attention to it was at a disadvantage as compared with the "limited liability man" and the man who did not understand his business. All practical men knew that there was not a railway in the kingdom, and hardly a steamer, that had not some defects, and it was in the careful watching of these defects, or supposed defects, that good management consisted. Accidents, in spite of every precaution, would sometimes happen; and if a vessel was unaccountably lost, it might not be easy for practical engineers and shipowners to get into the witness-box and prove their innocence. Their very carefulness might tell against them. He thought that the Board of Trade had done a great wrong to every practical shipowner and engineer, putting him in a position of personal danger that the ignorant man was not made to share. Shipowners deserved better treatment than that. The practical men who had helped forward the progress of steam shipping during the last quarter of a century were not quasi-criminals. They ought to be allowed the credit of wishing to do right, and should not be discouraged from giving personal attention to their business by such legislation as had of late years been adopted.

Mr. Bruce Bell wished to say a few words on behalf of the Clyde shipbuilders. The Author had written a lucid and complete

summary of the progress of twenty-five years in steam shipping and marine engineering, and the result at which he had arrived with regard to economy of fuel was, he thought, pretty nearly true. Much waste had been prevented, and minuter refinements were now needed, which could only be accomplished by improvements in detail. One point, which no doubt had effected the greatest change, was the introduction of steam of higher pressure; but here the interference of the Board of Trade had, as in many similar cases, hampered improvement. In stating the advantages possessed by the screw propeller, the Author had mentioned that of indifference to rolling; but it possessed one disadvantage in even a greater degree than the paddle, which was its inequalities of action in the case of pitching. This had been remedied to some extent by the application of the governor, but the great defect in governors hitherto in use was that they did not anticipate the racing action of the screw, and only began to act after the engine had actually commenced to race. A most efficient governor which acted by anticipation, was that of Mr. Dunlop, of Port Glasgow, which worked by means of a siphon and small air chamber in the stern of the vessel, the air of which was compressed or expanded according to the depths at which the stern was submerged or free, action being communicated to the throttle-valve accordingly. One of the most important matters to which the Author had called attention was Government interference with the details in construction of boilers and engines, and the vexatious and, in many cases, absurd rules proposed by the Government surveyors. Engineers and shipbuilders on the Clyde took up the matter some years ago, and sent to London a deputation who had an interview with Sir Charles Adderley; but as yet he was not aware that anything had been arranged. He cordially agreed with the suggestion that the Institution should give its aid in endeavouring to put some check upon that unnecessary interference, which had led to no other result than hampering improvement and producing irritation and annoyance. He might instance the case of spring-loaded safety valves, and ask if anything could be more absurd than the continued and determined opposition to their use at sea, where only a moderate pressure was used, when every high pressure locomotive in the kingdom was fitted with nothing else, although pressed to a much greater extent, and subject to much greater liability to accident. When it was considered that, at every roll of the ship in a heavy sea, the angle at which the ship lay relieved the weight of the valves from one-third to one-fourth, it seemed incomprehensible how such opposition could be

made to the discontinuance of so clumsy a system as dead weight loaded valves. It was true that the Clyde shipbuilders persevered in the use of the spring-loaded valves; but they were forced to reduce the load by 10 per cent. over what was allowed for dead weight. It was surely sufficient without exercising such paternal influence, and endeavouring to teach shipbuilders and engineers their business that the surveyors should simply keep to their duties in watching the proper construction and in testing the strength and stability of the work when completed.

Mr. QUELCH was surprised to find that Mr. Bell had fallen into a mistake with regard to the spring safety valve. He had drawn out and made spring safety valves for vessels that had passed under the supervision of the Board of Trade, and it would be seen on reference to the rules and instructions to surveyors, issued by the Board of Trade, that a rule for spring safety valves was given. It was a well-known fact that such valves were now used.

Mr. R. GREAVES desired to say a few words from the point of view of a master mariner. There had, he thought, been an omission in reference to one point. There had been a considerable degree of excitement lately on the question of whether the man at the wheel should be spoken to as a sensible being, having the handle of the rudder in his hand, or whether the rudder itself should be spoken to, or the direction of the ship's head be understood. Some might fail to see the connection, but a sailor would readily understand it. A right-handed screw would send the head of the ship to starboard, and a left-handed screw to port; and if the helm was not moved before the ship had got stern-way, the action of the rudder was not so quick and lively as it otherwise would be. In the event of two ships steaming at the same rate of speed, side by side, the one with a right-handed screw and the other with a left-handed screw, this would arise. If the ship on the right hand side of the other had a left-handed screw by which her head would be cut to port and the other ship on her left had a right-handed screw, the helm in each ship being steadied amidships, these vessels would infallibly collide or clash, because the ship with a right-handed screw being cut to starboard, the collision would be due to the united effect of the screws, each vessel's head being cut round in different ways. If, however, the vessel on the right hand had a right-handed screw which would cut her head to starboard, and the vessel on the left of her had a left-handed screw which would cut her head to port, these two vessels would separate, describe a circle, and again arrive—their paces and all other conditions being equal—in the same positions, relatively to one

another, as at first. In navigating a canal and particularly in passing vessels, this fact became most important. Every screw steam vessel should have a tell-tale indicating how she carried her helm, and a notice on the binnacle that her screw was left-handed or right-handed, and in all cases of collision this point should be brought out. If two vessels were steering the same course, side by side, the one with a left-handed screw and the other with a right-handed screw, their respective helms would be apparently opposed to each other, and the observant spectator would be puzzled, until he discovered that the helm was used, in each ship, to counterbalance the cutting round of the ship's head by her individual screw. He ventured to ask why any ship should have a left-handed screw? There was certainly great danger in it. If he did not know what kind of screw a vessel coming towards him possessed, he could not tell what her master was doing; but if he knew that the ship had a right-handed screw, he could then keep all square. He had lately brought this subject to the attention of the superintendent of a large company in the East Indies, who appeared to be ignorant of its importance. He had seen a ship belonging to that company alongside a rather heavy floating hulk. While she was there she had changed commanders. The commander who went on board had been accustomed to a vessel with a right-handed screw, and no one had told him that his new ship had a left-handed screw. He accordingly proceeded to handle her in the same way as he would have done his last ship, and the result was that in the act of leaving the hulk, while the tide was running with some force, his vessel's head cut round in the opposite direction to that which he intended; she thus did about £500 worth of damage. This was sufficient demonstration that the question was of a practical character. In 1847–8 there was considerable excitement in getting up the Royal Mail Company, and all sorts of inducements were held out to the public to subscribe for shares. He himself joined that company which had a Royal Charter of Incorporation, and a subsidy. At that time a subsidy was looked upon as a great matter, because the industry had yet to be developed, and there was no certainty of success, or probability of an immediate dividend as the trade had to be exploited. All the vessels under the charter were obliged to be so built as to be capable of being rendered serviceable in case of war. Subsidies developed companies, and companies had sometimes unwisely developed competition against themselves, by over-extending their own operations as if they were going to grasp their profits with both hands. He knew such a company in Liver-

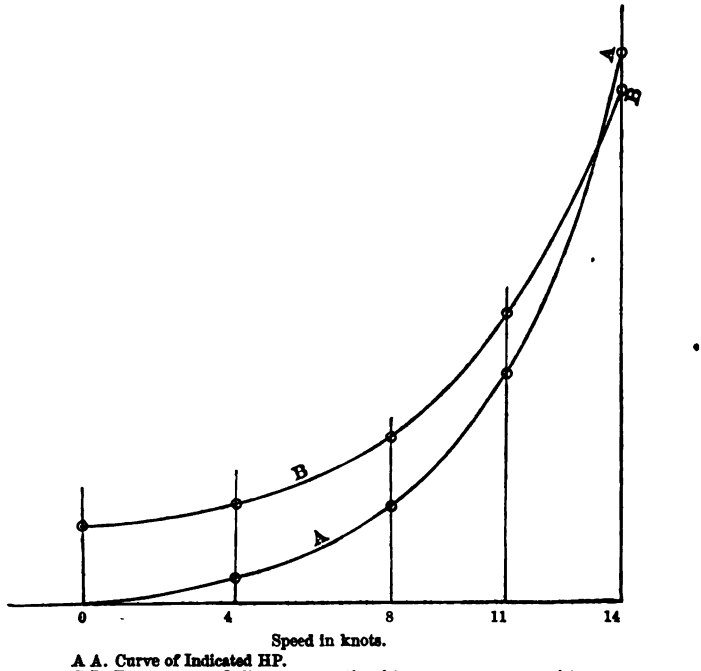
pool at the present moment. There was another reason why vessels had sometimes hung unprofitably upon owners' hands. Great Britain had ceased to develop her colonies as she should have done; had she not failed to develop the national estate there would have been an ample and ever-widening field of employment for vessels which had become somewhat *passé* in the original industries for which they were started. With regard to the interference of the Board of Trade, some persons thought the subject a delicate one, but he saw no delicacy attaching to it. It was a matter that concerned every Englishman, especially every man concerned with a keel. The function of Parliament was not so much to legislate in the first instance, as to inquire how far existing legislation was adequate, and, in the next place, to see how the enormous powers conferred upon the Board of Trade to carry out legislative enactments, were exercised. If the Board of Trade failed in its work, he believed it was in a great measure due to the fact that it resisted an investigation, such as was made periodically in every well-conducted administrative department, and also in all great mercantile houses. If the Marine Department of the Board of Trade was not exercising its powers usefully, it should be put into Commission, and the method of the work should be reformed in the spirit of the law. With reference to what had fallen from Mr. Scott Russell on the subject of the screw, he wished to say that he had been concerned in designing, building, launching, equipping, and sending to sea a small screw steamer, built on the edge of the bush in New Zealand. She was not a bad model, and travelled 12½ or 13 knots under canvas, but was slow under steam, her power being but small. During the time he was in the vessel it constantly occurred to him that the pitch and diameter of the screw ought especially to be studied with regard to the form or run of the vessel. It would be an act of folly to bore into a wood of long loose fibre with the same shaped auger as would be used in boring into wood as dense as teak or oak. It therefore appeared to him that what was wanted was a screw that would get the greatest resistance on the water just where the water would allow it to exercise its full power. There were two threads of water, one on either side of the vessel, and it was into those threads that the screw had to bore; now to bore effectually there must of necessity be a good set. He fully appreciated what Mr. Scott Russell had said upon the subject. If greater attention were paid to jacketing cylinders and casing boilers, there would be much greater economy. He had heard, however, that the jacketing of cylinders was really

a sham—that it was not done thoroughly and properly, and therefore no economy was derived from it.

Mr. FROUDE said there was one point to which he desired to call special attention, namely, the importance to a body of engineers of contemplating the questions raised in the present discussion, from an engineer's and not solely from a shipowner's point of view. To a shipowner the main question was, whether his ship would perform a voyage with a diminished consumption of coal for the same tonnage. The engineer, on the other hand, would not look at the thing in the lump, but would rather separate the whole question of propulsion into the different elements on which it depended. He could best emphasise what he had to say on the subject by stating that, in virtue of the experiments which he was conducting for the Admiralty, and which had given decisive results, enabling the true resistance of ships at various speeds to be ascertained, it was known that of the total HP. expended in propelling a ship, the useful expenditure of power—that which was simply due to the delivery of so much force at so much speed—did not in general amount to more than 37 or 40 per cent. When it was considered that such an enormous loss was taking place, it might well be desired to look into all the elements on which the expenditure depended, in order to see at what point improvements might be effected. He wished to refer to one circumstance in reference to the usual mode of estimating the merits of a ship, which he thought had been conducive to a great deal of misconception, and had retarded or misdirected investigation, namely, the way of expressing results attained in HP. simply, and not in propulsive force. He could best illustrate his meaning by describing what had happened in the analysis of certain interesting results brought forward by Mr. Denny, of Dumbarton. Mr. Denny had not been content with the usual mode of trial of his ships at what was called full speed, and half-boiler power, or half speed, but he decided that he would get a regular progression, from the highest powers he could deliver to the lowest, and correlate them with the speed of the ship. In that way a series of interesting results was obtained, and expressed in the form of a diagram such as that marked A A. The base line represented units of speed; the ordinate was HP., and the curve thus produced went through the zero of HP. at the zero of speed in virtue of the speed-factor in indicated HP.; but when the matter was separated into its constituent elements, a totally unexpected, but most instructive result was obtained. Dividing out from HP. the speed factor, propulsive force was obtained, or the equivalent. It was usual to represent

the work done by an engine by the product of the pressure on and the speed of the piston; but it might be described equally well on the supposition that no friction existed, by the product of the virtual speed of the screw and the force delivered by the screw. Now using the force factors thus deduced from Mr. Denny's experiments as ordinates, at each speed, a curve was obtained of the kind shown, in which the force ordinate refused to come to zero at the speed zero. The lowest speed was about 3 or

FIG. 1.



A A. Curve of Indicated HP.
B B. Force curve. Ordinates proportional to mean pressure on piston.

4 knots; and a fair curve drawn through the force ordinates given by the succession of speeds, instead of being a curve running down to zero, was a curve that terminated on an ordinate about $\frac{1}{4}$ of the maximum force ordinate, delivered at the highest speed. That, when looked into, represented the dead friction of the engine, the force required simply to turn the engine round when unloaded. A variety of ships was tried in that way, and all the curves, when analysed in the same manner, yielded about the same result. There were among them two sister ships on the same lines, and with as nearly as possible the same engines, and when the HP. curves

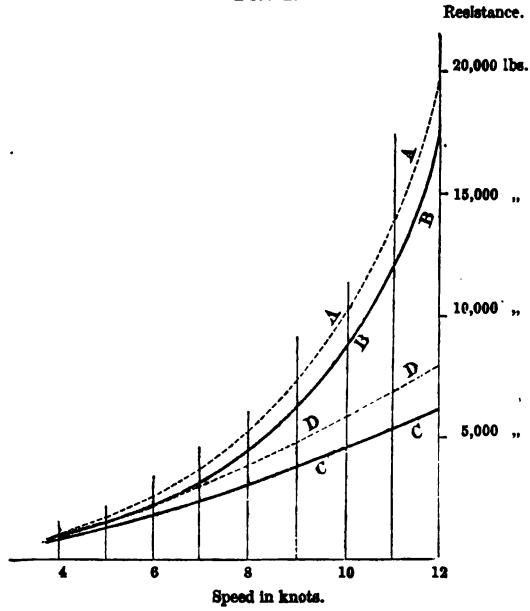
were produced, the result was very heterogeneous and incomprehensible, the curves intersecting each other, so that it could not be seen what their relation was; but when the alteration he had advocated was made, the force curves were precisely or almost parallel, showing a little excess of constant friction in the engines of one ship over those of the other, and giving a completely intelligible result. Those were two reasons why he thought it important to divide the subject into its elements. It would at once be seen that $\frac{1}{7}$ of the maximum force exerted by the engines was always going away in this particular kind of friction, and it was as great at the lowest speed as at the highest. That was a very heavy tax on engines which were fitted to work at a high power, but which were habitually worked at a moderate power. There was also another large element of friction due to the work delivered by the stress of the steam on the working parts. Take, for instance, the crank pins of a large marine engine. He had especially in his mind a ship, the indicator diagrams of which he had analysed. The crank pin was 22 inches in length, and about 22 inches in diameter; and it came out that when the engine was working at the highest power, and at its greatest speed, the work delivered in the shape of friction on the surface of the crank pin (assuming the co-efficient of friction to be $\frac{1}{15}$, which however, was possibly too high), was almost equivalent to a delivery of heat at the rate at which heat was delivered to the internal surface of a fire-box of a locomotive. The heat delivered at that rate had to be radiated away or got rid of in some manner by the crank arms and connecting rod brasses, but there was a great deal of heating and trouble with it. Then there were the packings of the piston and the like—all elements of friction, and each deserving separate investigation and study in order to see whether it was possible in any manner to reduce the loss. Again, there was another element introduced by a function of the propulsive force—the adventitious resistance produced in a ship's motion by the action of the screw propeller, where it was actually working. The screw propeller, working under the stern of the ship, pushed at the water, and propelled the ship; but in pushing at the water it made the water press less forcibly against the stern of the ship, and in consequence it produced a definite increment of resistance. By his Admiralty experiments he knew that in a great many ships that augmentation of resistance was as much as 50 per cent. He had no doubt that the common run of steamers had an adventitious or augmented resistance equal to 50 per cent. of their natural resistance, created by the very instrument that propelled them. It

might be interesting to point out the manner in which the fact had been crucially tested in the experiments to which he had alluded. The experiments were performed in a tank 300 feet long, with a working run of 180 feet, 10 feet deep, and 36 feet wide at the top, so that it was above all suspicion as to waves set up by the motion of the body. Just above the surface of the water was suspended a railway, with a 3-feet 3-inches gauge, and on that railway ran a truck carrying a very delicate dynamometer which pulled the vessel along at any assigned speed at which the truck was driven by a steam engine with a delicate governor. The model was held simply by the dynamometer, and by two delicate knee-jointed frames called guiders, so that the force measured was the pure, simple, propulsive force employed in driving the model. Everything was recorded on a travelling sheet of paper in the usual way. The speed was registered, as well as administered, and thus an exact record was obtained of the resistance of the model in terms of the speed at which it was run. It was run at a great variety of speeds, and a curve of resistance was obtained. The base line represented speeds, and the ordinates the resistances at those speeds. So much as regarded the determination of the model's natural resistance. Then as regarded the action of the screw, there was also provided the means of coupling up behind the dynamometer truck another truck, in which there was a separate apparatus—a suspended dynamometrical frame, from which there was hung, by a delicate bracket apparatus, a horizontal screw shaft, at an adjustable depth below the surface, protruding forward in front of the truck, and carrying a screw which was speeded to any speed, by a belt driven from the wheels of the truck. If that pair of trucks was run without a model, the screw could be urged at such a speed that it would exactly cut the water edgeways, without producing propulsive force or reaction, or any other speed so as to produce any thrust which it was capable of exerting. A diagram was made showing the pull of the screw on the dynamomitive screw frame, and also a diagram of the force administered by the belt, to make the screw turn round. This was a test to ascertain whether the screw was working neutrally, or whether it was in effect stripping the thread in the fluid nut and exerting propulsive force. Having set the screw to cut the water exactly, so that it simply went edgeways through it, the model was then coupled up in front of it, and having previously ascertained the resistance of the model at the given speed, it was seen what happened when the screw was brought into such close juxtaposition with the model, not touching it, but so centrally placed, and at such a level, as that it would be

at the place it would occupy if it were propelling the model. The screw in that position was still driven with exactly the same speed as that at which it had previously been merely cutting the water, without exerting any propulsive force at all when there was no model in front of it and the water was undisturbed. The introduction of the model at once produced two results. The screw was now exerting large propulsive force, equal to about 20 per cent. of the previous resistance of the model, and the model itself exhibited a considerably increased resistance: instead of pulling only about 3 lbs. at the tow rope, it pulled nearly 3½ lbs. Repeating the same experiment, and speeding the screw higher and higher, there was obtained a greater and greater propulsive force delivered by the screw, and at the same time a greater and greater augmentation of the model's resistance; and there came at last a point at which the screw's growing thrust had overtaken the augmented resistance of the model. There was then a state of things in which if the screw had been attached to the model, as if forming part of the complete system of propulsive machinery of the model, it would be running at such a speed as precisely to drive the model at her existing speed. Then the augmentation of the model's resistance varied somewhat according to various circumstances which had to be taken into account, the fineness of the run of the model, the thickness of the stern post, whether there was a false stern post behind the screw or not—all those things had to be taken into account, but the result was that, assuming the ship to have an ordinary fineness of run, there was an augmentation of resistance of from 40 to 50 per cent. He did not wish it to be supposed that the models were mere toys; they were boats of from 10 to 25 feet in length; they were manufactured exactly to lines and loaded exactly to their proper displacement, so that it was possible to compare the result of their resistance with the resistance of the ships they resembled and deduce what the latter would be. By some of those experiments it had been ascertained that there was the extraordinary waste of power to which he had referred, 37 per cent. being all that was realised. He might be permitted to mention a reason why he confidently stated that the results obtained by the experiments were true. Some years ago he had to conduct for the Committee on Designs a series of dynamometric experiments with an old corvette, which had the reputation of being a good sailer and steamed fairly. The ship was tried at her normal immersion, her normal trim, and varieties of trim by the head and stern; she was also tried at two other separate immersions, light and very light, so that the trial made with that ship was virtually

a trial with a great number of ships. He wished to show how the actual result thus obtained with the ship corresponded with that indicated by her model. The curve of resistance for the ship, as obtained by the dynamometer, was a curve like the curve AA shown on the diagram. The curve of resistance obtained by the experiments with the model is shown by the curve BB. The model was tried with all the changes of trim and of immersion that the ship had gone through, and it was found, in every instance, that the

FIG. 2.



A A, curve of ship's actual resistance.
B B, curve deduced from model for ship if with skin clean painted.
C C, curve of ship's skin friction if with surface clean painted.
D D, curve of ship's skin friction if with one-fourth part coated with calico over the paint.

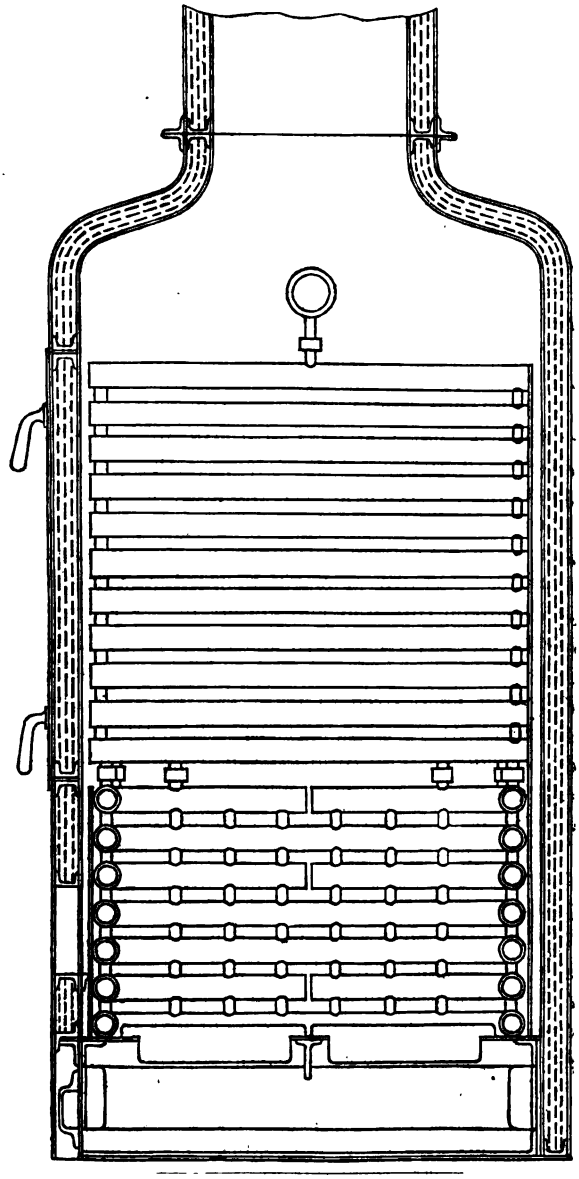
resistances exhibited by the ship with varied trim and of immersion were reproduced, under the same variations of trim and immersion with the model, almost exactly, but with fairer curves. The dynamometrical results obtained with the ship, though slightly irregular, because it was difficult to get the exact speeds, yielded fair average curves possessing characteristic differences; for instance, they showed that at a high speed the ship did better when trimmed by the stern, and that at a low speed she did better than when trimmed by the head. All those characteristic results were reproduced by the model. The curves, though much alike,

implied by their slight difference that, judging by the model, the ship ought to have made rather less resistance than she did, and *primâ facie*, it might be thought that that was evidence of some incorrectness in the indications given by the model. The interpretation of the descrepancy, however, was the following: a very large proportion of the total resistance, whether of ship or model, consists of surface friction, and is measurable in each case by the area of immersed skin, the quality of its surface, and the speed; and an extensive series of experiments had therefore been conducted to determine the co-efficients of resistance for surfaces of various qualities. This series, however, did not include old rough copper, such as that of the ship. The ship's resistance was, in the first instance, calculated on the supposition that the quality of the surface was equivalent to that of smooth paint, and it was the resistance thus calculated that fell short of the truth. It was probable that the rough copper had a more resistent surface; and at all events the difference would have been exactly obliterated if it had been assumed that a strip of ordinary unbleached calico had covered one-fourth part of the surface of the paint. On these grounds he ventured to state that the experiments with models gave a correct measure of ship's resistance, and that in virtue of that measure it was possible to determine how much nett HP. a given ship should require at a given speed, and from numerous comparisons between this and the actual power required, to state that, in a general way, an amount of only from 37 to 40 per cent. of work put into the engine of a screw ship was actually realised. The moral which he desired to draw was the great importance of separating, as far as possible, the expenditure of power into its constituent elements. The Admiralty had instructed him to work out a design for a dynamometer which might be substituted for the screw at the end of a screw shaft to measure exactly the power given out at that point by the engine; and he had succeeded in contriving one somewhat of the nature of a turbine, which, tested by a couple of good-sized models of different dimensions, justified him in the belief that a circular drum or casing about 5 feet 6 inches in diameter and 2 feet 6 inches in length along the screw shaft might contain a turbine, which would take up 3,000 HP. when rotated at about 90 revolutions. He was expecting an order from the Admiralty to get such an instrument made, and in that case the apparatus would be applied and made to record the actual power delivered at the screw end of the shaft by the working engine.

Mr. LOFTUS PERKINS said that engines of his design were now working with steam at from 350 to 400 lbs. pressure in tubular

boilers (Fig. 3), which appeared to have a long life.[1] They were

FIG. 3.



[1] *Vide* Institution of Mechanical Engineers, Proceedings, 1877, p. 117.

worked with distilled drinking water or rain water. The samples exhibited were those which the Admiralty Boiler Committee had cut out of boilers worked in that manner for eighteen years; it would be seen that they had not deteriorated. It had been stated by the Author of the Paper that jacketing was of no use; but it had been found that the greater the expansion the more necessary it was to provide the cylinders with jackets. Engines with low-pressure cylinders would stand the jacketing with high-pressure steam, 450°, without injury, and the economy was increased by keeping it at that temperature. In working with those high temperatures it had been found necessary to get rid of grease and oil, and a metal had been discovered which required no lubrication. In the course of six months a number of such engines would be at work, so that their capabilities at sea could be ascertained. It had been objected that rough sea usage would injure them, but he did not believe that long voyages would give any trouble. The most troublesome voyages to marine engines were the short ones, and the engines that suffered most were those that were worked on rivers. The expense of keeping in order the engines of passenger ships on the Tyne was equal to the whole remaining expense of maintenance. A boiler worked at sea was fired perhaps once in thirty or forty days, and did not suffer from expansion and contraction. The boilers that suffered most were those fired up twice or three times a day.

Mr. JOHN DIXON regretted that the Author had but little hope of future economy in the consumption of fuel. It was true that the consumption had been reduced from 6 to 4½, 3, 2½, and (in some exceptional cases) to 2 lbs. per indicated HP. per hour. But heat and mechanical force were synonymous terms, and it was well known that 1 lb. of coal ought to produce much more power than was realised from it. Theoretically 1 HP. ought to be produced with ½ lb. of coal, and though that result might not be attained, he thought the consumption might be reduced in a material degree. He did not agree with the Author in thinking that any further saving must lie in the reduction of wages. Engineering talent and the extension of the naval service had produced an increased demand for luxuries, and hence wages must inevitably continue to advance. Wages, however, might be materially economised by the use of steam for a great part of the somewhat laborious work on shipboard. The Americans had gone far ahead in that direction by the use of donkey engines and other appliances for economising labour. He could see no reason why steam should not be applied in

steering, and also in the stoke-hole, in the trimming of the coal and the like. With regard to the attacks that had been made upon the Board of Trade, he thought that those who attacked any public department ought to suggest a remedy for the evils of which they complained. He also thought that a public department like the Board of Trade might do something towards establishing new standards that would be useful to engineers. How many members present could tell what a nominal horse-power was? He was sure he could not. The Author had expressed regret that the steam trade of England had not been very remunerative; but seeing the extent to which the leading firms had increased their steam shipping, and the extent to which the steam shipping of England had been augmented during the last twenty years, it was surely taxing the credulity of the Institution to say that the trade had been a bad one.

Captain Bedford Pim, R.N., M.P., said the mercantile marine of the country now numbered some twenty-five thousand ships, of which not five thousand were steamers, showing, he thought, that the Author was mistaken in stating that steamers were entirely superseding sailing ships. Having been a great many years at sea, and having seen a great deal of the mercantile marine and the navy, he had no hesitation in saying that the mercantile marine was even of more importance to the country than the Navy itself. Two-thirds of the food of the country were imported from abroad; in fact, an addition of 40,000 tons of shipping was required every year, due alone to the necessity of supplying the new mouths, which increased at the rate of two hundred and sixty thousand per annum, the metropolitan area alone adding to the population about thirty-five thousand souls a year; hence the importance of seeing that the mercantile marine was efficient, not only in ships and engines, but in men, most of whom he was sorry to say were foreigners. He held in his hand a model of the long steamship of the present day, but only nine times her beam for length, whereas ten and eleven times were common. It must be evident to any one who had been at sea what would be the fate of such a vessel if an accident happened to her machinery, and she fell into the trough of a sea in a gale of wind. He maintained that she must inevitably go to the bottom. He also exhibited a model of a ship of the same tonnage, but of proper proportions, four times her beam for length. The long vessel was, no doubt, a fine one for the shipbuilder and the naval architect, but it was a bad one for the shipowner, requiring one-third more iron and materials and heavier scantling. It required also more repairs

than the other, going through the waves, instead of over them. A glance at the long narrow model would prove this, for a ship must seek her displacement, and if her ends rested on two waves the sea in bad weather would break inboard on both sides, both forward and aft at the same time. If the ship was waterborne by her middle the strain was excessive, and the sea broke inboard amidships with great force. Under any circumstances the long narrow vessel was unsatisfactory, the original cost was higher, she rolled more, she made worse weather, the cost of repairs was more, she was a bad sea-boat, and if an accident happened to the screw in a heavy seaway she was helpless. From a list of wrecks during the present year it appeared that about two hundred ships highly classed were missing. When such a ship went to sea most persons would exclaim, "What a magnificent ship she is"; but at sea, in a heavy gale, a slight accident would render her unmanageable, and then no sailor could keep her from going to the bottom. Formerly, when there was a collision at sea, the carpenter could repair the damage, and a brush of paint did the rest; but it was now far otherwise. With fewer ships than twenty-five years ago the number of collisions was greater. One reason for this was the inordinate length and narrowness of our ships. He would like to point out to the meeting that the power of the rudder was in inverse proportion to the length of the ship, and that when a captain saw another vessel approaching dangerously close he gave orders to stop, without reflecting that the rudder ceased to act almost as soon as the screw stopped. He did not care to speak on the scientific aspect of the question, but merely as a sailor, and he regretted deeply to see the rubbish now launched, both as to design and material. He remembered being in the Arctic regions, in company with the old "True Love," which was built in 1764, and was on the Register at the present moment, being fit to go to sea and encounter any weather; while several whalers were crushed she withstood the pressure of the ice. The Author had stated that until the advent of steam there had been no improvement in merchant shipping from the time of Julius Cæsar. A sailing vessel at that time had only one huge mast and one sail, like the vessel in which St. Paul was shipwrecked, and which was "undergirded"; but it was rather incongruous to compare such a ship with a sailing vessel of modern times. Besides that, it was not until thirteen hundred years after the time of Julius Cæsar that even rudders were invented. With regard to the speed of sailing ships, eighty years ago a frigate went from Quebec to Portsmouth in eleven and a half days. He could not

but express his regret that naval architects were not to be found who could really design a ship somewhat better than that of the model which he had exhibited.

Mr. PHIPPS asked Mr. Froude to explain one or two points with reference to his dynamometer. The first was as to the growing power as the water kept travelling from one cell to another out of the turbine. How would Mr. Froude manage if it were required to maintain a constant force upon the recording spring for some five or ten minutes' observation? It appeared to him that unless the pressure were modified by shutting off the water by the shutters between the turbine and the fixed part, it must be undergoing a constantly increasing "potential." He also wished to ask whether there was not a great deal of leakage in the lateral division between the moving turbine and the fixed part, there being merely a mechanical fit of the two edges; and, further, whether there was not a considerable centrifugal pump-like action when the apparatus was set to revolve in the water around it.

Mr. FROUDE replied that the growth of resistance was all completed in the first two or three revolutions. When the thing was begun to be turned at a stated speed it made more and more resistance, until the total force employed in driving made up a force equal to the frictional resistance of the water; so that it was only for a second or two that the force remained a growing one. As to the disruptive action of the separating forces of the two parts, each complete turbine consisted of a pair united back to back, so that they pushed merely against opposite sides of one case. There was one large case embracing the turbines, and if it were strong enough no difficulty would happen. With regard to the rotation of the water, that was all inside the turbine; it would not happen outside; the strain on two casings would be simply measured by a lever brought to a spring and registered in the usual way.

Mr. PHIPPS said he had given a good deal of attention to the measurement of the resistance of vessels and the great loss of power by the presence of the screw too near the ship. In a Paper read by him in the year 1864,[1] he had referred to that matter, and said that a ship and screw ought to be considered as one compound machine; that the minus resistance occasioned by the screw pushing that water away which ought to be helping the ship behind, was one great source of the loss of power. On that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii.

point Mr. Froude had, he believed, made many experiments, putting the screw on the shaft at a considerable distance from the stern, and obtaining superior results. The Paper to which he had alluded was mainly directed to an attempt to ascertain what was really the friction of the skin-resistance of ships. Up to that time it had been a common doctrine that resistances on ships' surfaces and in pipes were not comparable; but he believed he succeeded in showing that, while following the same general law, the coefficient for friction was greater in the pipe than on the surface of a ship, when the conditions of smoothness and nominal velocity were the same in each. In the Paper now under discussion, the utility of the indicator diagram had been, as he thought, unnecessarily depreciated. He was of opinion that the comparative merits of two sets of engines could be sufficiently well determined by a careful examination of the indicator diagrams, coupled with the consumption of coal, both taken over a sufficient length of time, without any reference to the dynamometer. The difference of power exhibited by this instrument and by the indicator could only be that due to the friction of the shaft bearings and other moving parts, which with engines of average good construction, in good working order, would not, he thought, amount to any large proportion of the whole power; and it should also be borne in mind that the considerable amount of friction occasioned by the thrust of the screw shaft against its bearings was not measured at all by the dynamometer. He was inclined to the opinion that the greatest possible difference of friction would often exist between trials of the engines with the vessel at rest, moored in a dock, and when in actual motion at sea, owing to the working of the vessel, and consequent bending of the propeller shaft, leading probably to its frequent fracture. With regard to the interference of the Board of Trade and other public bodies, he did not think it was any disadvantage to have certain rules laid down for the guidance of those concerned. For instance, the rule of 5 tons to the inch laid down by the Board of Trade for railway girders was a useful one, putting engineers more on a level, and preventing their employers from complaining about unnecessary weight of the parts. The effect might be to a certain extent to stop inventions; but was not that often a wholesome one? In regard to the introduction of steel, for instance, it would not have been an advantage to have had it used for ships too soon. Mr. Barnaby came to the conclusion that it could not be trusted, although now he believed he was building a ship of that material, and it was well known that if holes were punched in certain kinds of steel the whole plate

was rendered useless. Was it not a great advantage that Government had not adopted steel until after more experience had been gained through the experiments of Dr. Siemens and others? But for the delay, the use of steel might have been retarded for many years.

Mr. J. R. RAVENHILL wished to draw attention to the increase of tonnage in the mercantile navy registered in London in 1876 as belonging to the British empire. In 1854 there were 326,452 tons of steamships registered; and in 1876 the figures had increased to 3,293,487 tons. At the latter date there was a total of 584,106 nominal HP. During the past five years there had been an increase of 158,000 HP. He regretted the Author had not given further details as to the great changes that had taken place during the past twenty-five years. The iron vessel twenty-five years ago was an accepted fact, and the screw propeller had, some time before that, proved its vast superiority over the paddle-wheel. From the time when H.M.F. "Niger" was fitted with a screw, and H.M.F. "Basilisk" was fitted with paddle-wheels, and they were lashed stern to stern, and started in opposite directions, the screw propeller established its superiority, and was accepted by engineers as the future mode of propulsion, except in cases where, from want of draught of water, or other necessities, the paddle-wheels were still adhered to. If the vessel to which he had alluded had been fitted with feathering wheels, the advantage of the screw propeller would not have been quite so great. He also wished to direct attention to another series of Government experiments, in the early days of iron vessels, on board the "Minx," "Teazer," "Rifleman," and "Sharpshooter." The "Minx" and "Teazer" were sister ships of about half the tonnage of the "Rifleman" and "Sharpshooter." One of each of the pair of vessels was of wood, and the other of iron; and the same lines were adopted in each case as far as the use of wood would allow. The superiority of iron as a material for shipbuilding was clearly demonstrated. The lines that were finer forward no doubt assisted in the result, but greater benefit was found from the fine lines aft which the iron stern post enabled the builder to adopt. The result was that the iron vessel with half the power went the same speed as the wooden vessel with double the power. One of the largest subsidised companies built an iron vessel in 1843; in 1844 they ordered four vessels of 1,800 tons each and 450 HP.; and from that time to the present they had only ordered three wooden ships. The Admiralty also at that time showed their confidence in iron as a material for large

ships, for they laid down the screw frigates "Vulcan," "Megæra," "Termagant" and "Simoon"; and although, before they were completed, experiments had shown that iron was not suitable for vessels of war, they were completed as transports, and afterwards did good service. There could be no doubt as to the advantages of the compound engine. He had read a Paper touching on the subject in August last, at a meeting of the Institution of Naval Architects held at Glasgow, in which he had given figures showing that the commercial advantages obtained on every ton of coal expended in the use of compound engines under the present system, over the ordinary jet-condenser engine working with 20 or 30 lbs. pressure on the boilers, varied from 126·2 per cent. to 54·8 per cent. The Author had stated that there was now less incentive to further economy than there once was with regard to the consumption of coal, and that shipowners were turning their attention to other items. There he joined issue with him. Coal was still a point to which the owner must look, for reduction in the consumption of coal meant decrease of labour, not only in trimming the coal from the bunkers to the stoke-hole, but also in feeding the fires with it. The remarks of Mr. Froude were most valuable, and had led up to a point on which he believed he could give some interesting information. Mr. Froude had spoken of the enormous loss by friction in large marine engines. If that friction could be reduced, coal would be saved. During the last few months he had examined a plan of bearing which had been successfully used in the crank pin brasses of the White Star packets running between Liverpool and New York. It was, he believed, an American patent; it consisted of an ordinary pair of brasses studded with pegs of a patent white metal, somewhat similar to that in use in this country. The brasses as originally fitted had those pegs of considerable diameter. The pegs had, however, been increased in number, and wherever a hole could be drilled between the original ones smaller pegs of white metal had been introduced. The brasses were in the first instance bored out in a lathe to a smooth surface. Experience had shown that the white metal expanded somewhat more freely than the brass. The ends of the pegs thus projected a trifle above the brass. On looking at the brass he could not help being struck with the fact, that when once the bearing became properly lubricated, any oil that got amongst the pegs could hardly get out. It was well known that with a jump on the brasses the oil would go, and it was difficult, with a large pair of engines, especially when they were first started, to get them to go without

some jump. Those bearings had stood the test of many months: they were composed of pegs of white metal, the interstices being filled with oil. Formerly a set of brasses used to be worn out between Liverpool and New York, and they had been a source of much trouble on each voyage, but now they ran continuously without any trouble at all. The same kind of surface was also being used for guides, and he could see no reason why it should not be used for the main bearings. If that were done a vast stride would be taken towards the extinction of hot bearings, and towards the further reduction of fuel. Indicator diagrams were no doubt interesting to engineers and to scientific men. At the same time the shipowner only looked at the matter in a broad view, as to how much cargo in cubic contents, or how much dead weight could be carried over a given distance at a certain speed for a certain weight of coal. That weight had to him a known money value. It was a commercial diagram of which he thought more than any indicator diagrams received from the engine-room. Allusion had been made to the "Great Britain." She was a wonderful ship; she had been greatly altered, no doubt, from the time when she passed the winter in 1844 in Dundrum Bay before her great success in the Australian trade; but she was certainly most regular in the performance of her voyages. Her speed was about 8¾ knots, and he well remembered her coming into dock at Liverpool, and whilst standing on the quay alongside the men saying to him, "She is so punctual that we sets our chronometers by her." With reference to auxiliary ships, the speed of the fleet of Messrs. Wigram had increased about 1¼ knot beyond this, say to about 10 knots per hour. Such hitherto had been the service to Australia. Within the last few weeks a ship had been placed on the Pacific line the average speed of which all the way to Melbourne had been 12·96 knots per hour, one of the greatest feats in steam navigation. The Author had drawn attention to the expense of subsidies. There could be no doubt that subsidised companies had rendered good service to the country; and he believed it was the boast of the Peninsular and Oriental Company that, although their mail bags had on one or two occasions been submerged, the mails had never been totally lost. The companies had been trammelled by the ships being fitted to carry guns—both the Peninsular and Oriental Company and the Royal Mail Company. The Cunard Company might have had a somewhat easier time. With all their faults, those companies had greatly assisted the allies during the Crimean War, and had done good service during the Indian Mutiny. There was one point connected with the subsidies

with which he had been greatly struck. He held in his hand an abstract of tenders offered for the conveyance of the West India mails, dated 28th January, 1874, printed by order of the House of Commons, and amongst the names of the parties who tendered on that occasion he found that of Mr. Alfred Holt. No doubt the Author would explain his reasons for having so suddenly changed his mind. The supervision of the Board of Trade had, no doubt, in the first instance, been established for the purpose of survey. All the earlier Reports tended to show that intention, but latterly it had to some extent been departed from. Connected for the last few months with the Wreck Commissioners, it had been his lot to sit between the Board of Trade, the shipowner, the engineer, and the public, and he had listened with great pain to the remarks made against the Board of Trade. If any change was to be effected, it would not be brought about by hard words; and it should be remembered that the officers of the Board of Trade had frequently very onerous duties to perform.

The Author had made an allusion to a little book from which he should like to make a quotation. A great deal of unpleasantness had arisen as between some parties connected with the engineering world and the Board of Trade. Up to a recent period engineers made their own boilers and never went near the Board of Trade —everybody did what he thought right—then the Board of Trade officials said that they did not agree. It was suggested that the thing should be taken into consideration. It was represented to the Board of Trade that boilers well constructed, well designed, and made of good material, should have an advantage in the matter of working pressure over boilers inferior in any of the above respects, as unless this is done, the superior boiler is placed at a disadvantage, and good workmanship and material will be discouraged. The Board of Trade surveyors have endeavoured for some time to take all these points into consideration in fixing pressure, and for this purpose the following Rules were prepared, and at the request of engineering firms subsequently circulated."[1] He ventured to suggest for the serious consideration of the Board of Trade, and with a view of throwing oil upon the troubled waters, that when a great change was proposed, such as had recently taken place by the introduction of high-pressure steam, they should ask the manufacturers to send three or four selected representatives to consult with three or four officials from the

[1] Instructions to Surveyors of Ships. Clause 90. Cylindrical Boilers.

Board, adding two or three gentlemen who were acquainted with marine matters. Such a conference would thresh the subject well out, and a small committee taken from amongst them might be formed to frame rules. The manufacturer would then know who framed the rules. It was often said at the present time, "The rules may be all very well, but we do not know who framed them. We are told to do this, that, and the other, and we cannot help ourselves." The Author had alluded to surveys connected with railways as compared with surveys connected with steamers. He did not think that a locomotive ever ran twelve hours without stopping; and certainly none of its parts were as massive, as heavy, or as liable to be deranged as the heavier parts of a steamer. But what did the Board of Trade say? "You may do as you like with your locomotives; we will take care of your permanent way." The walk of an ex-railway official from Bristol to Exeter would long be remembered. But what about the other permanent way? The Board of Trade never determined when a ship was to go to sea and when she was not to go to sea; and they were wise in not doing so, otherwise they would have been inundated by letters from people saying, "Why did you subject us to the horrible inconvenience we suffered the night before last in crossing the Channel?" In the case of a ship leaving for a round voyage the survey of her machinery should be most complete; but while he would argue in the strongest manner for a survey, survey should not stay progress. He had during the last few months seen ships and machinery, such as he had had no idea were in existence, trading round our coasts. They were a disgrace to the present day, but unfortunately they could come under no survey. Owing to certain clauses introduced into the Merchant Shipping Act, they were exempted altogether from surveys of the Board of Trade, and to a great extent of Lloyd's. With regard to the progress of steam navigation, one of the greatest strides that had been taken for a long time was the introduction by the London, Chatham, and Dover railway of the steel mail packets, "Samphire," "Maid of Kent," "Scud," "Petrel," and "Foam," of 340 tons and 160 HP., and 503 tons and 240 HP., when they commenced their Channel service in the year 1861. They had stood the test well. The hulls were still in perfect order, and the result ought to give confidence in the introduction of steel in vessels. He had lately seen in some steel works a forging for a connecting shaft with a cheese coupling, which had proved a complete success. Three years ago one of the leading steel houses attempted a

similar thing, and, after three failures, had been obliged to give it up. No allusion had been made to the patent metal of Sir Joseph Whitworth. That metal, like many other things, came in at a timely moment when engineers were troubled with the cutting that was taking place in the high-pressure cylinders of compound engines. As far as experience had hitherto gone with that metal, it appeared to be a decided success. Sir Joseph Whitworth had also introduced hollow propeller shafting of the same metal with a considerable saving in weight in the total length of shafting on board large screw steamers; in fact many tons were saved, and that, of course, meant a saving of coal, because there was less weight to be carried. No reference had been made to the introduction of the twin screw; and he thought that the history of the last twenty-five years would not be complete without some allusion to it. It might not have been used much in the commercial marine; but its advantages were often so great that it was worth passing notice. He had seen a vessel built and fitted with a single propeller tried against a sister ship fitted with a twin screw. In the one case a very small disk area of propeller was obtained in proportion to the midship section of the vessel, and in the other case a large disk area. The vessel with the twin screw beat her sister ship by more than $1\frac{1}{4}$ knot an hour. What was wanted in these high-pressure days was a new form of boiler, with all its parts accessible for the purposes of repair and examination. He had seen several cases in which serious accidents had taken place, and no one had any idea that the iron had been reduced in thickness from oxidation so materially as it was. The reduction took place in the water spaces round the bottom and sides of the fire-box, which it was very difficult to inspect. It had been recently stated that a new mail service was to be commenced on the 1st of January between Liverpool and New York, to be carried on by the White Star, Inman, and Cunard Companies in concert. They were about to carry mails three times a week, and he was much mistaken if the service would not be carried out at the speed exceeding 15 knots. The White Star Company had, during the last four years, led the way with reference to the Transatlantic service, but other vessels had been built which were fast treading on their heels, and he was not sure that the Inman Company had not made one shorter passage than the White Star. With such a result the Holyhead service, which had been for so many years pre-eminent, would be cast into the shade. He observed a drawing of the safety valve of the steamship "Sidonia." The boiler explosion on board this vessel had

been the subject of an inquiry before the Wreck Commissioners in July last, at Edinburgh, and he trusted that that form of valve, or rather that application of the weights, would be abandoned. There was a Salter's spring balance at the end of the lever. The Board of Trade took exception to it, believing that if the spring gave way there might be trouble; that the lever would fly up and the steam escape. Means were then contrived by which a weight could be lowered, and although he believed the alteration was not considered entirely satisfactory it was accepted. The weight was fastened up in the vessel by means of chains and padlock. The padlock was under the charge of the captain and chief engineer, as were all padlocks connected with safety nozzles on board ship, but it was proved to the satisfaction of the Court that the engineer had not only fastened down the safety valve on the superheater, but had lowered the weight on to the lever to bottle up the steam, so that the boiler was carrying, as nearly as possible, double the amount of pressure that it ought to have carried.

Admiral SELWYN observed that the question under discussion, at all times an interesting one to Englishmen, was doubly so now, since the support of the nation depended much more largely than formerly on its commerce. Our staple industries and work of every kind had found rivals who could not be met in any other way than by continued progress, and he confessed to a little disappointment with the Paper to find that, while speaking enthusiastically of former progress, the Author had put the small limit of 25 per cent. to the progress of the next twenty years. He should have occasion to speak of a great improvement which had more than quadrupled all that the Author hoped might be obtained in twenty years, but of which he did not appear to have taken any notice. An advance had been made from 600 to 6,000-ton steamers; from 20 to 80 lbs. pressure; from 4 lbs. of coal per indicated HP. per hour to 2 lbs.; from £40 freights for steam to India to 40*s.*; from 108,321 tons of steam shipping belonging to Great Britain in 1850 to 1,847,588 tons in 1875; from a 10-knot speed to 15; from wood to iron; from iron to steel; from 6 beams to 10, with equal safety and greater comfort; from misery to passengers to the nearest approach to luxury that could be expected at sea. He utterly denied the Author's statement that monopoly was a bad thing and had done more harm than good. Young trades, like young trees, required protection, which however was injurious to both after they had attained maturity. At first it was impossible to set on foot such enterprises as those of the Atlantic steamers without some such

protection as had been given to them. There was a good deal more work of the same kind to be done, and he should be sorry to see a principle accepted which would put a stop to the most unobjectionable form of Government interference. The interference of the Board of Trade was only injurious when it took the dicta of men of high standing and great experience, and transformed 6 to 8, as factors of safety, into lbs. per square inch. When new materials were obtained, or a new disposition of those materials, it was clear that the 6 to 8 factor would remain true and correct; but when translated by the Board of Trade into so many lbs. per square inch the interference became a very unwise one. There was, no doubt, a tendency to over-legislation —to consider every man a rogue until he had been proved to be an honest man, and the result was that many men found themselves forced into a corner, and had to compromise with honesty. The Author had principally complained that there was not sufficient advance in economy to enable the trade of which he had spoken to be carried on at a profit, or that the profits were very uncertain. The diagrams and tables placed by Mr. Perkins on the walls, however, afforded an answer to everything that he could say on that subject. It was to be regretted that Mr. Perkins had not spoken more fully of his invention, but he was known to be a very modest man. Admiral Selwyn was himself one of those who looked forward to progress in steam shipping as the only means by which the country could maintain its position. He knew that in that Institution there could be no sympathy with the idea of "rest and be thankful." Mr. Perkins had asked him on one or two occasions to go with him in his little steamers. The only thing that astonished him (for he had studied the subject before) was that the engineer desired nothing so much as to blow up his boiler. He had himself turned the steam on the back of his hand at 500 lbs. pressure, and it produced a sensation rather of cold than heat. Here was a boiler which, by the new disposition of material alone, had achieved that safety for which all had been looking, under very high pressures, while at the same time it had achieved durability. At those high pressures and under that condition of steam peroxidisation took place on the interior surface of the tubes, and they remained the same after thirteen years' wear. It was no new thing; it had been proved by a Boiler Committee, who had stated that it was the only known solution of the problem; yet the thing did not seem to go forward—he hoped only because it was not more widely known. The economy of fuel obtainable by this boiler,

which required only 1 lb. of fuel per indicated HP. per hour, was easily understood, when it was remembered that instead of a water-box at a temperature of about 220°, with the highest pressure in use at present round the combustion-box, there were a number of tubes containing steam at a much higher temperature, much more nearly approaching that of combustion. There the fuel could be got to burn as it ought to burn, which it never did before. The burning of the fuel was also conducted in a boiler of much smaller size than any previously used, when they were considered simply as water-boxes with fires inside them. It was also a great advantage that it could be supplied with a casing filled with vegetable black, which prevented the heat being felt in the stoke-hole. Naturally, from engines, though they might be jacketed, there would be a certain amount of heat; but if the boilers were properly constructed, there would be no reason why the stoke-hole should not be even cooler than the engine-room. Taking 5,000 lbs. pressure on the inch as the test, he presumed the idea would be dismissed that even if the boiler could burst, it would be likely to burst at 500 lbs. pressure, at which it was intended to run; but when it was remembered that even if it did burst, one tube only was spoiled, and all the gases inside escaped almost without noise, and certainly without damage to the vessel or crew, it would be admitted that that was an enormous advance. With regard to the compound engine which the Author had put forward as the great improvement during the past twenty-five years, he had spoken of it when it was not in so much favour as it appeared to be at the present time, but he never made the mistake of thinking that the compound engine was the real source of the economy. He had known from the first that it was due to nothing more than increased pressure, and that if improvement was sought it might possibly come to pass that the compound engine would be done away with altogether; it might be found that while the pressure in the boiler was increased economy was obtained, no matter what kind of well-devised engine was employed to develop the power. His attention had been drawn for some time past to the causes of decay in boilers, and he found himself obliged to acknowledge that there was a chemical action going on which had not been spoken of before the Committee on Boilers, or in any other way. He had studied the matter in some chemical works, and believed he was able to give a consistent explanation of the causes of that curious form of decay in boilers called "pitting." It would be found in Watt's Chemistry, and elsewhere, that chlorine invariably passed over as an accompaniment of the

distillation of salt water, and it attacked certain parts of the boilers which were not homogeneous, and were more liable to its effects than other parts. Having so attacked it the water-vapour present, particularly at the higher temperatures, transformed the chloride immediately into an oxide, liberated the chlorine again, and enabled it to recommence its action; thus pitting might go on at one spot completely through the boiler. The ordinary way of preventing it was to let a small scale get on the boiler, but that was an unsatisfactory method. It was better to understand the chemical part of the question, and to know what to prepare for, than it was to injure the heating surface in some parts in order to protect it in others. With regard to the outside, of course it only took the place of any other preventive of radiation, but with reference to fire-boxes, a very thin coat of scale produced evil effects, which ought by all means to be avoided. There were several experiments, some of which had been made by Mr. Bramwell, showing that in the boilers on the Perkins system used for heating water in houses, and for other purposes, on opening the boiler after a given time of running, there was an escape of pure hydrogen. That hydrogen certainly did not come in through the pumps as gas; it came because at the high temperature to which it had been exposed water was so far decomposed into its constituent gases as that the oxygen could combine with the iron, with vegetable substances, or with anything for which it had a greater affinity at that temperature, and which it was usual to call "scale preventers" and "boiler protectors" when they were put in. Thus combining, the oxygen deserted the hydrogen, and that, he thought, was the only way to account for the presence of the latter in the uncombined state. For the present he submitted it rather as a theory than as a proved fact; but in the current number of the "Engineer" an account would be found of experiments in America devoted to the proof of what he had stated. If Mr. Perkins's boiler would give high pressures (the necessity for which appeared to be universally acknowledged) without danger —if it gave to naval officers the power of repairing boilers at sea and without cutting their ships to pieces, and gave at the same time an engine requiring no lubrication, and occupying a comparatively small space, if by a little chemical attention any defects that might arise (which, however, Mr. Perkins asserted would not arise) from ordinary leakage in the fresh water originally supplied might be remedied, the subject surely was not unworthy of the attention of the reader of a Paper on the progress of steam shipping, and might give him reasonable ground to hope that all previous improve-

ments might be thrown into the shade by what we now actually have in our own hands. The matter, he was happy to say, was no longer in the domain of an inventor's unaided efforts, nor even of Government solicitation; it had passed into the hands of a gentleman, Mr. George Crawshay, whose name was well known for actual practice.

Mr. COWPER would have been glad if the Author had descended a little further into details; the mechanical part of the question being of more interest to the members of the Institution generally than the commercial part. There were several steps, however, in the progress of improvements that took place more than twenty-five years since, and to which he should like to refer. The Author had mentioned three steps—iron ships, the screw propeller, and the compound engine. With all deference he ventured to suggest, that the raising of the pressure of steam was at least as important as any one of those three steps; certainly as important as the compound engine, because without it the expansion could not have been carried so far as it had been, and such powerful engines could not have been constructed in so small a space. A beginning was made as early as 1835, when Spiller's boiler first came out, capable of containing working pressures of 5, 10, and then 24 and 40 lbs. Mr. Spiller, with Mr. Zander, had a small boat called the "Era," with an engine working at 40 lbs. pressure, and they had also a compound engine with a small cylinder to one crank and a large one to the other, and the cranks at right angles, as far back as 1841. Steam navigation might certainly be said to have begun in 1836. Before that time Dr. Lardner had prophesied that the Atlantic could not be crossed; but in 1836 the "Sirius" and the "Great Western" actually did cross it. Then came the "British Queen" in 1838, the "President," the "Archimedes" in 1840, and the eight Royal Mail steam packets in 1841. Spiller's boiler had water inside the tubes and fire outside, and they soon gave rise to the present form of marine boiler, with water outside the tubes and fire inside. One of the earliest was made by Mr. Maudslay, and others were made by Mr. Braithwaite. His "Prince Albert" had Spiller's boiler at first and then the marine boiler. The boats he had referred to were all driven at a greater pressure of steam and going at a considerably higher speed than before. The "Princess Alice" was another of Mr. Maudslay's boats which did well. Then came the quick boats on the Thames, and afterwards the first fast Mersey boats. By 1846 the old Spiller boiler had gone, and the marine boiler had taken its place; but before this, his friend, the late Mr. Alfred Milner, had made a marine boiler

with fire in the tubes, and with a cylindrical shell for 30 lbs. pressure; this boiler, when sold as second hand, burst from bad treatment at considerably over 100 lbs. per square inch, so that strong high-pressure marine boilers of a reasonable shape were made as early as this. The Samuel Hall's surface condensers, invented in 1833, followed, though not much in use before 1838, when they did good duty in the "British Queen," after which more attention was paid to them. Later on, steam jackets began to be used to a limited extent, as the advantage to be obtained by their use was not then fully understood. The "Link-motion" was another good step in improvement. The common form of compound engine, with a small cylinder to one crank, and a large one to the other, the cranks being at right angles, succeeded. A friend of his had such an engine in use on land about 1844, and several times the low pressure engine was entirely broken down from the high-pressure steam getting through from the high-pressure engine into the low-pressure, and he requested him to put the matter right. He accordingly put a steam-jacketed "steam reservoir" between the two cylinders, and he believed that was the first time that such a steam reservoir had been used, although now they were so common, and did such good duty, entirely preventing the low-pressure engine ever being strained when the reservoir was properly fitted with a large safety valve. The engine was successful, and he afterwards introduced the same contrivance into other engines on board ship, and on land. He also had the honour of persuading Mr. Elder to put the cranks at right angles, a process attended with great effect, obviating the necessity of having six cylinders, two to each engine, but simply requiring two cylinders, one to each crank. Then the "Briton" and the "Thetis" were fitted by Messrs. Rennie on Mr. Cowper's plan, and in those vessels the saving which the Author looked for, during the next twenty-five years, had been actually accomplished. Instead of 2 and 2½ lbs. of fuel per indicated HP. per hour being reduced 20 per cent., a reduction had been already made from 27 to 35 per cent., for they had worked full speed at 1·98 lb. of coal, and at 10 knots at 1·3 lb. The steam in such engines should be cut off and expanded in the high-pressure cylinder, and should always be cut off at or before half stroke in the low-pressure cylinder, otherwise a second portion of steam from the high-pressure cylinder passed into the low-pressure cylinder, thus uselessly filling up space, and throwing away power. If the steam was cut off at half stroke in both cylinders, the most uniform power attainable was produced. The Author had held up the

compound engine as one of the grand steps that had been taken in late years (and so it was); but he wished to ask, whether he had not, since 1872, had many engines with single cranks and a fly-wheel. He believed fly-wheels, about 12 feet in diameter and 7 tons weight, had been found very useful for getting over the centres, but they would hardly have been found satisfactory in practice without a very quick and effective reversing motion, consisting of an ordinary "link-motion" moved by a steam cylinder, moderated in its action by a "cataract," or water or oil cylinder, which rendered it very easy work to handle the engines. He thought that the members would be glad of the opportunity of discussing that form of engine if the Author thought it a better one commercially than a compound engine with a single cylinder to each crank, and the cranks at right angles. He was informed that many of them had been made, and that more were still being made.

Mr. J. L. K. JAMIESON said that all practical men connected with marine engineering would acknowledge that they were under a debt of gratitude to the Author for bringing forward so interesting a subject. They would also, he thought, agree with him that nothing had contributed more to increase the commerce of the country than the compound engine as applied to the propulsion of ships. If there was any point on which he would be inclined to find fault with the Paper, it was that the Author had not given sufficient credit to two men, John Elder and Charles Randolph, who had fought the battle when there were few people to help them. It was in 1854 that the screw steamer "Brandon," fitted with their compound engines, went to sea, and in 1856 the paddle-wheel vessels "Inca" and "Valparaiso," fitted with compound engines, were sent to the Pacific. There were few people who knew the history of the compound marine engine so well as himself, having been Superintendent Engineer for ten years of the Pacific Navigation Company in the Pacific, and having been connected since that time with Randolph, Elder, and Company, and the firm of John Elder and Company. The diagrams, taken from the engines of the "Bogota" in 1860, with two 48- and two 90-inch cylinders, and 5 feet length of stroke, indicated nearly as good results of any that could be obtained of engines in use at the present time; the pressure of steam was 25 lbs. in the boilers, and the condenser was of the ordinary jet description. The consumption of coal was 2½ lbs. per indicated HP., and might be considered a good result at an early period of the compound engine. Owing to an accident happening to one of the low-pressure pistons, the engines of this vessel were worked for several months with three

cylinders, and the diagrams shown from the high-pressure cylinder of the disabled engine would be considered a good figure from an ordinary low-pressure condensing engine. Whilst the engines were working in this condition the speed of the ship had been reduced, and the consumption of fuel increased about ¼ compared with the performance of the four cylinders, thus showing a marked economy in favour of the compound engine. The history of the compound engine and its rapid adaptation to all classes of steam ships were now well known, but he wished to support the Author's appeal to the members against too much Government interference, and the necessity of protesting against it. There was no such interference by the Board of Trade twenty years ago, and if there had been he was firmly of the opinion, that compound engines would not now be in use for the propulsion of steam ships. The interests and the reputation of marine engineers throughout the country were at stake. At present it was impossible to move out of the track the Board of Trade had instructed their surveyors to keep without encountering difficulty and annoyance. He had no fear of progress being made in the future in marine engineering, as well as had been done in the past, if the individual talents of those engaged in it were left unfettered. The Institution of Civil Engineers might do much good by protesting against such interference as limited the individual talents of the engineering profession, and presented that progress which was likely to take place when not cramped by a Government department. It might be necessary to bring the whole matter before Parliament.

Mr. Moy stated that up to the present time the great aim of the marine engineer had been to produce the highest possible figure of indicated HP. per lb. of coal consumed. But Mr. Froude had brought to the front another important item, which must never again be neglected, namely, dynamometrical thrust. He had roughly sketched a vessel, in which the indicated HP. was marked as 10, while the useful effect was represented by a weight attached to a rope and the figure 4. Suppose the engines to be consuming 2½ lbs. of coal per indicated HP.; at 13 knots an hour this would represent 10 lbs. indicated thrust per lb. of coal, but the useful effect was only 4 lbs., that was 4 lbs. multiplied by 1,320 feet per minute was all that could be got out of 1 lb. of coal. It therefore became very important, not only to obtain the highest possible indicated HP. per lb. of coal, but also to reduce the enormous difference between these two figures 10 and 4. That friction of machinery had much to do with this result there could not be a doubt; but he thought that the screw was very much at

fault, and he would endeavour to point out one of its faults. The case of a right-handed screw propeller might be considered, the ascending blade being on the port side, and the descending blade on the starboard side. The pitch being the diameter multiplied by 1·25, the angle might be about 22°, or 68° from its line of axis. Now if all the water about the run of the vessel moved in parallel horizontal lines, this propeller would act as desired. But the water would not do so. The current approached the screw obliquely, and the screw acted on that oblique current in a manner not intended. The water rushed up under the vessel, approached the port blade at right angles, and at some speeds it would simply have a back action instead of a propelling action, because, relatively to the current of water, it had no pitch at all there. On the other hand, the starboard blade, when in a horizontal position, struck the ascending current of water at an angle of 44°, the pitch being increased to about three times the diameter. At the intervening points in the circle the blades acted obliquely on the ascending current. He thought, therefore, that the effect which he had attempted to point out accounted for a considerable portion of the 60 per cent. loss which was sustained, and it also accounted in some cases for what was called negative slip and the loss of many propeller blades. The remedy was to place the propeller shaft in a line with the natural current of the stern water, and the propeller, of course, square to it. It would be necessary to get rid of the awkward construction called "screw alley," to have a short and strong propeller shaft, and to reduce the 60 per cent. loss, and that meant less power, and therefore coals saved. He thought his point was proved by the success which had attended the trials of Griffiths' tubular screw channels, for they directed the current square to the propeller. About twenty years ago he proposed making the upper end of the rudder the broadest part: he now ventured to put it also square to the stern current, and to attach the tiller to the after end of it.

Mr. JOHN DONALDSON said that the Author had confined his attention to vessels in the merchant navy to the exclusion of vessels built for purposes of war, owing, no doubt, to the fact that the improvements referred to were applicable to both classes of vessels, and that the results of their application were obtainable in both cases. Of late years, however, a new type of war vessel had arisen, and it would be a pity that the discussion should close without some notice being taken of it. He alluded to the fast steam launches designed by Mr. Thornycroft some years ago, which were now being made with some modifications by his own firm as torpedo vessels for the

English and several continental navies. They were similar in many respects to the vessels described by the Author, being built of steel, and fitted with compound engines and surface condensers, and having, what the Author desired so ardently, locomotive boilers, with steam at 120 lbs. pressure, and also with spring safety valves. Strangely enough the proportions that had been found by the Author to give the greatest economy in vessels in the merchant navy had been proved by his firm to be best adapted for high speeds. Their vessels were usually about $7\frac{3}{4}$ beams in length, and Mr. Froude, in some experiments on the "Lightning," had shown that that size gave the best results. In the 58-feet type they had attained a speed of $15\frac{5}{8}$ knots per hour, in the 67-feet type 18 knots, in the 76-feet type $18\frac{3}{4}$ knots, and in the 84-feet or "Lightning" type 19·4 knots when the vessel was light, and $18\frac{5}{8}$ knots when she was loaded. There were no very accurate data with regard to coal consumption, the efforts of the firm having been chiefly directed to the production of high speed. The results he had mentioned were not founded on mere measured-mile trials, but on runs of from one to two hours' duration. In some vessels which they were completing for the French navy they had undertaken to maintain a speed of 18 knots per hour for three consecutive hours. In their early steamers the blast was laid below the fire-box, but it was found that this gave rise to many inconveniences. Ultimately they closed up the stoke-hole, and forced the air into it, so that the only exit for the air was through the furnace. In some of their vessels his firm had used 8 inches water-pressure in the stoke-hole, when they had been rather pressed for steam; but their best results had been obtained with about $2\frac{1}{2}$ inches water-pressure. He had heard of the excellent results obtained by the Author's steamers while in the East, and should be glad if the Author would give some information with regard to coal consumption, and also the proportions of his vessels and engines.

Mr. J. MacFarlane Gray said it had given him great pleasure to listen to the Paper, because, in addition to the high value of the statements it contained, it happened that, when the Author began to use compound engines, Mr. Gray, then with a Liverpool firm, had to see his first design carried out in the first engine of the firm, now known as the Holt engine. One of the speakers in this discussion had tried to make out that the Author was more of a shipowner than he was either an engineer or a shipbuilder; now he would take this opportunity to state before engineers that the Author was also so much of an engineer, even in points

of detail, that the design for that first Holt engine was substantially complete in arrangement and proportions as it came from him. He thought that the forecast of probable further reduction in the cost of the HP. as stated by the Author was a very just one, and none could give from better information what had been the rate of improvement in the past. Although he concurred in the Author's views he would not say one word to take away from the sanguine anticipation of Admiral Selwyn, because he thought there was really no difference between the two. The Author, no doubt, reading the practical lesson contained in the experience of the "Propontis" and other experiments in higher pressures had concluded that doubled or quadrupled pressures were not for his steamers in the immediate future. If the higher pressures shown to be so very manageable in the Perkins boiler were commercially practicable, then the economy anticipated by Admiral Selwyn would no doubt result. From 20 lbs. of coal per hour with surface condensation there should be obtained the following, 6, 8, 10, 12, 14 HP. at 40, 80, 160, 320, 640 lbs. absolute pressure. The first two steps in this series are taken from the Paper. If in addition to the higher pressure there should be also an increased furnace efficiency, giving a higher rate of evaporation per lb. of fuel, then 500 lbs. pressure might give double the present efficiency or 16 HP. from the 20 lbs. of coal per hour, which, according to the Paper, now gave 8 HP. A great deal might be reasonably expected from the arrangement described by Admiral Selwyn, and he hoped that the Author would turn his attention to it because if it was a practicable system it would then probably soon be fairly tested in a merchant steamer. Admiral Selwyn had stated that the Perkins boiler was found to contain much hydrogen when it was opened after long use. The decomposition of water vapour in contact with iron at ordinary steam temperatures was a fact not so generally known as it ought to be to engineers. He had heard Professor Frankland state that this decomposition never occurred but at a temperature very much above what occurred in the steam boiler. The hermetically-closed spaces of steam pistons after the engine had been in use a year or two, contained so much hydrogen that explosions to the injury of workmen had frequently happened. The first time he had this brought under his notice was about 1863, in Liverpool. A man boring, to put in some additional bolts for a junk ring, lost his sight through the gas in the piston exploding when it came in contact with the flame of a candle. Several other similar instances had been reported to him. With reference to engines not compounded, competing in economy with

compound engines, engineers naturally looked to America where the long stroke single cylinder was doing good work. It had been his good fortune to be present, during her first trip, on board the "Hudson," a steamer of this description lately illustrated in the "Engineer." There were two circumstances in connection with that vessel well worthy the attention of the engineers of this country. Here the bearings had their keeps fastened with large bolts having threads of a coarse pitch. When a bearing became heated an engineer was apt to slack back the nuts too much, and often the heating was thereby increased. In the "Hudson" and the other vessels of the same company the old form of gib and cutter had been retained, and one turn of the small nut at the end of the cutter would alter the distance of the brasses perhaps only 0·02 inch. The fine adjustment led to great carefulness on the part of the engineer. This means of accurately setting up the brasses would be of no avail unless time were given to enable the engineer to try what was the best distance for the brasses. The owners studied this need, and the first trip of the "Hudson" was made with only half the boilers in use. The first voyage it was intended should also be made with only half-boiler power. The object of this was to give the engineer time to deliberately adjust every bearing without being troubled with several hot bearing at the same moment and to get the engine to work without the slightest thump. The engineer of the company, Mr. John Baird, a gentleman who was most willing to give every opportunity for inspecting the engines to engineers from this country, explained to him that their company, the Cromwell Line, never hurried them in getting up the speed. They knew the speed would be the greater when they did get it if it took six months with reduced boiler power to enable them safely to get up to it. How strange it would seem in this country if an Atlantic steamer intended to beat all others in speed, should be sent several voyages with her boilers not all in use, and her first voyage with only half-boiler power! It might, however, be a wise course to follow, and it would lead to the saving of thousands of pounds in repairs. It was not only that the bearings were scrupulously cared for after they were in the steamer, they were finished in the lathe with even greater care. Every bearing of the crank shaft was finished absolutely true with the corundum wheel, and this was carried out to exactly the same degree of accuracy as was their practice with the rollers for paper mills. He spoke according to what he had seen and tested at the works at Wilmington, where the engine of the "Hudson" was made. In the course of this discussion, Mr.

Froude's conclusions on the ratio of useful effect obtained had been referred to. In the sense in which "work" was understood in mechanics, there was really no useful result whatever obtained from the marine engine, and there was therefore no fraction of the power applied which was absolutely unassailable for increased economy. Mr. Froude had shown how great was the loss by friction in the moving parts of the engine, and the American engineers seemed fully to appreciate that fact, and to be taking the best way of reducing that element of loss. In the principle of the engine he thought the American single engine for the screw propeller inferior to the English compound engine. He formed this opinion from examining the diagrams taken from the "Hudson's" engine. The excellent result undoubtedly obtained was, he believed, in a great measure due to the diminution of loss by friction in the engine by greater accuracy of workmanship and extravagant carefulness in working. The Author had spoken disparagingly of steam jackets and indicator diagrams. Steam jackets ought not to be indiscriminatingly dealt with as if all were under the same conditions. About twelve years ago in Liverpool an assistant of the Author and himself received from the manager of the works of Gebrüder Sulzer, of Wintherthur, a careful statement of results obtained from an elaborate series of experiments made to settle the steam jacket question. The pith of the conclusions was that up to four expansions in one cylinder a steam jacket was of no advantage. When the multiple of expansion exceeded 4 the advantage of a steam jacket became apparent. As in the Author's steamers the expansion in one cylinder did not exceed the ratio 4, this experimental deduction did not seem to be interfered with by the Author's experience. Indicator diagrams must also be treated discriminately; he had implicit faith in diagrams, but he seldom met with any one who understood them. He had questioned hundreds of engineers on diagrams, but he had seldom found one who could read off from a set of cards what the effective pressure was at any marked point in the stroke. This state of knowledge perhaps accounted for the little faith some engineers placed in the diagrams. A valuable illustration of the usefulness of diagrams had frequently come under his observation. Some of these also revealed how a steam jacket might possibly become a real evil. In the complicated castings of which jacketed cylinders sometimes consisted, a core plug was perhaps left out; or a contraction crack might exist which, when the cylinder was examined, might be so close that it was invisible, and even almost watertight under hydraulic test.

If such a crack occurred in the division between the steam jacket and steam ports the current of steam soon cut it wider. He had seen such a crack about 20 inches in length widened by the erosive action of the leaking steam, at the end of five or six years, to be about ¼ inch open at the middle. The diagram revealed the existence of this leak and indicated its locality. About boiler strength, the Author had been very severe upon the Board of Trade, and he had on a former occasion in a printed Paper, compared the practice in America with the pressures allowed by the Board of Trade, to show that the restrictions of the Board were oppressive to engineers and shipowners. Mr. Gray confessed to sympathising heartily with the Author and with every engineer who desired to make the most of his materials. It must be evident, however, that the feeling expressed in this discussion very much preponderated towards the stringent inspection authorized by the Board of Trade. In America, also, he was astonished to find that the engineers of eminence on the East Coast were almost all in favour of the proportion of strength prescribed by our Board of Trade. In the Western States the boilers were much lighter than ours, but the boilers now making on the East Coast for pressures, equal to those in use here, were substantially what would be passed by our Board of Trade for the same pressure. Some of these boilers had to pass also in this country, and it might be thought that this explained that fact. The war vessels, however, could not be meant to pass our Board of Trade inspection, and the eight vessels of the "Swatara" class, each with ten boilers for 80 lbs. pressure, had these boilers, substantially, just what would be allowed 80 lbs. pressure in this country. This statement was made upon personal inspection of these boilers in course of construction.

Mr. Holt, in reply, said he could at least claim for his Paper the merit of having provoked a very interesting discussion. Mr. Samuda had taken him to task for not having given honour where honour was due, and mentioned the name of Mr. Brunel. He desired to give a fair meed of honour to every one who had earned an honourable place in this great though unnoticed revolution, and if he had failed to do so he wished to make amends. He thought it would be a fitting thing for the Institution to have a record made before the facts were forgotten, for there were many persons who had rendered marked assistance, and whose names were seldom mentioned. Whether the compound engine could be traced back to Hall of Dartford he did not know, but he thought it probable that it could be so traced through the various steps of

Elder and Hick, who competed with Hall, at an early date, for the manufacture of compound engines for land purposes at Barcelona. Nor should the name of Arthur Woolf be forgotten, who enunciated the principle as early as the beginning of the century. Mr. Brunel deserved great praise, if only for the "Great Britain," an admirably built vessel, in which he made an excellent experiment with the screw, at a time when it was much wanted; but with regard to the "Great Eastern," he thought size was her chief peculiarity, and that there was not so much to learn from her as from other vessels. Considering Mr. Brunel's genius and the flow of capital his designs attracted, his only wonder was that she was so small.

At the request of several speakers, and not that he claimed for it any peculiar merit, he would now briefly allude to his own practice. When compelled to greater economy in fuel, he noticed that in many places the single engine was employed with absolute satisfaction; that in cotton mills, where regular turning was more necessary than in any other case, the single engine was frequently used. He had also observed that in America it was almost invariably used, and he accordingly resolved to try it. His first idea was economy of cost and space, and he believed that he gained in both. He had fewer parts, and fewer expensive and dangerous parts, the crank shaft particularly was much simplified. He apprehended at first some difficulty in handling and some risk of collision from not being able to reverse the engine when required; but every apprehension of that sort had turned out groundless, and having now had considerable experience with the single engine, and moderate experience with a double one, he thought that the former was rather more handy than the latter. Allusion had been made to a probable irregularity of motion owing to the force exerted by the engine at one part of its stroke being about one-third greater than the average force. That was so, scientifically, but he had never been able to perceive it, and he believed that the single engine turned the screw as regularly as the double engine. He made that statement after having watched them both attentively for a long period. He had always aimed at as long a stroke as possible, and a fair speed of piston, say from 400 to 500 feet per minute, according to circumstances, and light, strong, moderate-sized parts. He believed that a great deal of the power that was lost, and which loss found no expression in the indicator diagram, resulted from the great weight of the parts. He had been led to that conclusion by a simple experiment. If any one would take a heavy dumbbell in his hand, and try to work it quickly

backwards and forwards, he would find that there was an enormous expenditure of power, and he concluded the same was true of engines. He had been told that in some large steamers there were pistons 110 or 120 inches in diameter, weighing nearly 9 tons, with piston rods, cross heads, connecting rods, and other parts attached to them weighing altogether as much as 15 tons. Imagine a small locomotive in weight the equivalent of such a mass, brought to rest from a speed of 8 miles an hour in a space of 2 feet, and this repeated every half second. He imagined that by any one riding on it the process would be called a series of rather severe collisions. He could not but think that an enormous quantity of power was expended in this way, and he had accordingly aimed at lightening and strengthening the moving parts to the utmost. He had not aimed at extreme expansion, because it involved large parts. From 5 to 7 times was the expansion he had adopted with 70 lbs. pressure of steam. His engines were furnished with a fly-wheel, which was a very useful adjunct, even to a double engine. Damage had been apprehended from the use of high-pressure steam in the working parts. It had often occurred, and it had proved a difficult thing to get over. He had used for the high-pressure engine with success plug piston valves—simple plugs moving up and down, which were very nearly tight. He could not detect on the indicator diagram much leakage; they certainly required no power; and there was no liability to the cutting which often took place on high-pressure valve faces. His ships were from 1,900 to 2,300 tons, about 9 beams in length, with a depth of a little less than $\frac{3}{4}$ of the beam. They were rather finely modelled and lightly rigged. They were all in the China trade, and he believed his was the longest voyage in the world, being from 22,000 to 23,000 miles. He had noticed that one of them during a China voyage had had her sails set only seven hours, which caused him to conclude that he might safely rig his vessels lightly for the future. He had always provided ample boilers, and might say that he had never over-boilered or under-masted a ship. He obtained a speed of about $9\frac{1}{4}$ knots from a consumption of from 14 to 17 tons of coal per day on a voyage involving about one hundred days' steaming, and in consequence of consuming so small an amount of fuel he was often able to do the whole of his coaling in England. Mr. Merrifield, in commenting on the statement that carelessness about further coal saving was coming over shipowners, said that probably Mr. Holt was like the rich man who did not care about the quantity of bread consumed in his household. He denied the application of the simile; but if he, on the longest voyage in the world, was

beginning to forget the coal bill and direct his attention rather to other disbursements, it would only be natural that shipowners engaged on shorter voyages should be more careless still. Anyway the fact was becoming apparent that shipowners were now thinking less of coal consumption than they did only a few years ago. The recent fall in the price of fuel might have a good deal to do with it. He found that on the voyages to China the dues paid by him were sometimes 50 per cent. greater than his coal bill, and he only wished he could apply the compound principle to the Suez Canal. When hinting in the Paper at the probability of the single engine replacing the compound engine he had very much in his mind the practice of Mr. Baird, to which allusion had been made by Mr. MacFarlane Gray. The performances of the "Hudson" as set forth in the "Engineer" were certainly very wonderful, and he only wished he could be certain that they were correct. He believed, judging from the size of her boilers and furnaces, that the consumption would be about 26½ tons of coal a day; but the amount stated in the "Engineer" was 17 tons. He was of opinion that the danger arising from the admission of steam in a single cylinder, which seemed to haunt English engineers, was a phantom. In a well-constructed engine steam might be admitted at high pressure, on a moderate-sized piston, without injury. Probably one reason for the prevalent shortness of stroke in this country was the difficulty in forging crank shafts. If a 6-feet stroke like that of the "Hudson" were desired, the forging of the crank shaft would be a very serious affair. It was a question with him whether loose cranks would not come into use again. He remembered the time when all screw steamboat engines had loose cranks. Although the intermediate bearings might be a little sore, they never broke a crank or a crank shaft in those days. If the engines were placed a little farther apart, so as to get a long intermediate shaft and bearings sufficiently remote to be tolerably steady, the old system might still be found the best, and it would allow any stroke that might be desired, and also would admit of moderate-sized crank pins. Mr. Froude had spoken of an engine with a crank pin 22 inches in diameter and the same in length. All he could say was that a crank pin of that size could come to no good end. He had taken a voyage up the Mississippi in a vessel in which the steam was at 150 lbs. pressure, and the engines had two separate cylinders 32 inches in diameter and 12 feet stroke. Steam was allowed to remain on the piston about ⅔ of the stroke. That immense power was all taken through a 5½ inch crank pin, and it stood perfectly,

and kept quite cool, although no particular attention was paid to it. With reference to the indicator, the opinion he had expressed with diffidence was that it could not be implicitly relied upon. Much of the power shown by the card did not find its way to the propulsion of the vessel, probably because it was taken up by the actuation of the piston, and other heavy parts first in one direction and then in another. And again, if the indicated HP. was made up very largely of high speed of a short-stroked piston, or of excessive expansion realized only by large parts, he doubted that the power shown did not produce its due effect. Nevertheless the indicator was certainly a most useful instrument for finding out faults. He had been asked to account for his statement that boilers of the present high-pressure vessels were as durable as the old ones. He could only say that he had found them to be so. Very recently he had sent a vessel to sea which had nearly completed ten years' constant service, made by the house of which the President of the Institution was the head. It was originally designed for a pressure of 60 lbs. of steam, and was tested before going to sea on the present voyage with water pressure, and stood 100 lbs. without sign of failure. He could hardly perceive that the boiler wanted anything doing to it. Probably if one-eighth of it were renewed it would be as good as new. Mr. Flannery had justified the discrimination alluded to in the Paper, namely, that if a pressure of 120 lbs. was carried by the boiler of a locomotive, one of 70 lbs. would be a fair pressure for the same boiler at sea, and had said that the different uses of the two justified the discrimination. He joined issue with Mr. Flannery on that subject. He had inquired into the construction of a good many boilers, and found that every part of every boiler that he had got, except amongst the tubes, could be seen by an inspecting engineer with moderate ease. That could not be said of a locomotive. His knowledge in regard to locomotive practice was of rather old date, but it was formerly the custom to use locomotives without seeing the inside of the barrel until six or eight years had passed. He did not know whether that was the present practice, but certainly much more care could be taken, and he thought was taken, of steamboat than of locomotive boilers. It used to be said that in a fire-box, if the screw stays were recessed, so that there was a bulge between them, it was a matter rather to be proud of, because it was said the stays were coming to their bearings; if such a thing were seen in a steamboat boiler it would be remedied at once. With regard to the factor of safety for steamboat boilers he confessed that his mind had undergone a considerable change. He

had originally thought that 6 would be a fair figure, and that the Manchester Steam Users' Association, the Philadelphia Association, Locomotive Engineers, and others, were wrong in giving 4 and 3½: these asserted, however, that they had never had an explosion, and what more could any one want? Therefore, guided by the light of their experience, and considering the ease of examining steamboat boilers, he thought that a factor of 5 or even, after trying that a few years, a lower figure still might be safely adopted. Of one thing he was quite sure, viz., that the tension allowed on straight stays, 5,000 lbs. per square inch of section, might reasonably be almost doubled. It had been said that the factor of 6 or even 8 was the origination of Sir William Fairbairn, but it was no derogation to him to say that in his later years he was slightly inconsistent in this matter, and that if at one time he had given those as suitable factors, at another he had recommended much lower ones. With reference to the rules of the Board of Trade, except as to details and questions of degree, he did not find great fault with their principle but it was ten thousand pities that they had ever been issued, for they stereotyped and gave authority to questionable opinions on very debatable subjects; and on one point of principle he disagreed with them, viz., when they assumed the shearing strain of rivets and the rupturing strain of plates as equal. He was well convinced that the former was the greater. In his allusion to the action of Government in his Paper he was sorry that he had struck a chord that had awakened some feelings which he did not desire to arouse. He had, however, a heavy indictment to bring against subsidies, which had been to him a rock ahead through life. The system began about 1840, and some of the subsidies granted put an end to independent lines just coming into existence. Subsidies had thrown back the use of the screw propeller ten or fifteen years. The "Great Britain" was built in 1840, and though she was not perfect, she afforded a very fair trial of the screw. After one or two more trials it would almost have attained its present perfection; but simultaneously the system of subsidies was started —and it was the natural desire of all the holders of subsidies to pursue the safe, and avoid experiments—and hence they clung to the paddle wheel, knowing exactly what it might be relied on to do, and that though an imperfect wasteful instrument, its performance was accurately calculable. Subsidised lines in those days of few steamers naturally formed public opinion, and the result was that between 1840 and 1855 any one who used a screw propeller in a vessel of importance was considered a harebrained

experimentalist, not to be trusted. Subsidies could also be shown to have delayed the use of iron vessels many years. People would not have the boldness to differ from the great steamboat owners, who themselves would try nothing new, and hence fleets worth millions sterling were built, their designers and many of their owners well knowing that the vessels were not of the best description. Amongst them he might mention such vessels as the "Orinoco," "Arabia," "La Plata," "Parana," "Africa," "Amazon," "Demerara," "Asia," "Magdalena," &c. The duty of the Government in this matter was a narrow one. Imperial necessities must override private interests, but tenderly, and with steadfast aim to postal necessities only. There should be no side aim to cheapen freights or passenger fares. Wherever the Post Office authorities absolutely required to have letters carried, and there only so long as they could get them safely carried, it was their duty to do so without regard to the establishment of a magnificent line of steamers which was often an instrument of oppression and the stronghold of mechanical error. It had been said that he was inconsistent, because he had made an offer to convey the West India mails in 1874. It would be affectation on his part to say that he would not get a subsidy if he could, but the facts of this particular offer were as follow. He had been engaged in the West India trade years before that time, and had felt that the presence of subsidised ships was a serious disadvantage to other vessels; he accordingly thought that though he had left it, he would endeavour to relieve the trade of that bane, and he believed that the only escape for Government was that the letters should be carried in vessels that conveyed neither passengers nor cargo (the condition on which his offer was made), because then, the whole stream of commerce being uninterfered with, other vessels would speedily establish themselves into lines, and the Government at the end of his term need never have paid any subsidy whatever.

With reference to the question of inspection, it appeared to him that the Government and the public were at present pursuing an impolitic course. One half of England was setting itself to inspect the other half, and no one could tell what would come of it. He feared the process would in a generation or two result in an indisposition to undertake difficult enterprises, and would enfeeble invention. He had no desire to indulge in attacks on the Board of Trade, but every public body was open to reasonable criticism; he invited it for himself, and always thought a critic his best friend. The Board of Trade had entirely gone beyond statutory requirements. The intention was simply to have the opinion of

a surveyor as to the safety of ships, and not to enforce minute constructional regulations. By what plain motives could the action of the Board in the question of safety valves be accounted for? They had indeed admitted the use of springs, after years of incessant remonstrance, and spring safety valves were now employed; but under what circumstances? Such excessive size was required that the incredible fact on board his vessels was that the safety valves had about twice the area of the steam pipes. It was well known that at a high pressure steam passed with greater rapidity from an orifice than at a low pressure, yet if a boiler were made for 10 lbs. or 100 lbs., an area of ½ square inch of safety valve for each foot of grate bar would be the rule for both; the waste from that absolutely reasonless regulation was enormous. They had also insisted that the valve should lift one quarter of its diameter, and had thereby cast great difficulties in the way of designers, and all perfectly needlessly, for no such lift or anything approaching it in the remotest degree was ever required. The united action of the Board of Trade and the Legislature in the matter of safety valves had been mischievous throughout; there never was a difficulty on the subject yet with all the years of trouble they had given; a country blacksmith who called a boy from the plough to turn his lathe would to day make a safer, lighter, cheaper, less wasteful, and in every way better safety valve than their best. The Legislature, in a moment of philanthropy, had passed a law that all vessels should carry a lock-up safety valve. Mr. Thomas Gray had stated that the technical advisers of the Board of Trade disapproved of that law. He had been of a similar opinion for years, and there could be no doubt that a lock-up valve had led to the loss of life in the "Thunderer." A plain locomotive valve would have prevented the explosion.

The question of engineer certificates had been alluded to. He believed the enactment that they should have certificates had been injurious; he meant, had rendered steam navigation more unsafe. He of course could not tell what went on in public offices, but he believed the act was passed without public pressure at the instance of the Board of Trade, simply to enlarge their region of interference. There is no handicraft skill in being a steamboat engineer; a habit of constant attention to simple, somewhat monotonous duties, and the power to stand changes of temperature, were the principal qualifications required, and the present class of men, as a rule, did not, and were not likely to possess them. That enactment very nearly caused him at one time to abandon the trade.

He had been asked to indicate the direction he expected future improvements to take. At the head he put the endeavour, which he saw no reason to suppose would be unsuccessful, to obtain more effect from the boiler. A single ton of locomotive boiler produced as much steam as 6 tons of ordinary steamboat boiler, and some simple cheap mode of producing a keen draught without a steamblast (which was simply throwing away fresh water) was a desideratum. This more rapid combustion, if attainable, was evidently synonymous with a lighter boiler, carrying with it many savings. Next, the principle of hot blast, he thought, would come to the front, as a matter for probably successful experiment. Few persons appreciated the volume and heat of the current which went up the funnel, which, he suspected, though containing some carbonic acid gas, was mainly little else than hot air and unconsumed fuel; often this loss was accepted and increased as a simple mode of producing draught. Suppose this current were driven through a second fire, would not the hot blast effect be produced and the fuel burnt up?

The use of steel presented great attractions, the possibility of saving was so immense, but the question of reliability stood at present practically unsolved, he used the word "practically," because steel makers said it was solved; but they would hardly claim for the solution that it was not rather too delicate and scientific to meet general acceptance. Besides, he feared an objection would be taken to very light scantlings on account simply of their lightness. In hulls, more especially in skin plates —an amount of "obduracy" to be gained only by weight was required.

One of the greatest improvements in steamers would be the production of unbreakable shaft forgings; outsiders had hardly any idea of the cost, delay, and frequency of broken shafts. One recommendation he would give would be when a shaft broke to be sure that the bearings were in line, he feared untruth in them often broke shafts.

What future extension would the steam trade take? A slightly further invasion of the business of sailing ships might be looked for, but the principal extension would probably be in new directions. Generally speaking an increase in our enjoyment of the more perishable products of distant parts of the earth might be looked for. He took it that live cattle would be brought to this country in numbers hitherto unthought of. There was no mechanical difficulty in the way; the fear of government interference alone, he believed, stopped them being brought over from Texas

or the River Plate; there was no doubt some £5 from the former, and £6 from the latter would carry them if capitalists dared embark in the undertaking on a sufficient scale to make it successful. Oranges were a small matter, but this country was now beginning to have two annual crops instead of one as formerly, the second coming from south of the equator. A large extension in this class of trade might be looked for.

What it had not so far accomplished satisfactorily, numerous as had been the attempts, was the Channel service, and this was the more astonishing that the problem looked so easy. Whether the new "Castalia," a very fine and interesting vessel, will possess the four requisites—speed, steadiness, lightness of draft, and handiness—next year would solve.

He could not see that the future promised a better money result to the shipowner than the past. His would doubtless continue to be a business yielding different results to differing managements; but that the past average result, which he took it had been from 3 to 5 per cent., would be much exceeded in the future, was what he would wish and hope, but could not expect.

Mr. STEPHENSON, President, said, with reference to the indicator, statements had been made as to what it could not show, and it was only fair to the inventor to state what it could show. He for one believed thoroughly in the indicator up to a certain point. It gave the pressure of steam upon the piston throughout the stroke, and it was never intended to show what was going on inside the boiler or in the screw shaft. It told everything from the boiler to the condenser. It showed if there was a stricture in the pipe leading from the boiler to the cylinder, if the throttle-valve was too small, if the steam was wire-drawn, if the piston was leaking, if the cylinder was honeycombed or flat-sided, if the valves had too much lap or lead, and it told the state of the condenser. He thought, therefore, that the little instrument gave a very good account of the work done in the cylinder by the fuel consumed; and if it accomplished so much, it ought not to have been passed over by a reference to what it could not do, and to what it was never intended to do. With regard to the surface condenser, he had always felt great pleasure in giving credit to those who really deserved it; and while he gave all praise to Messrs. Randolph and Elder who had brought to bear on the subject an immense amount of talent and ingenuity, it ought not to be forgotten that had it not been for the surface condenser such high-pressure steam would not now be used as was commonly employed. He therefore

thought that the name of Mr. Samuel Hall might have been brought more prominently before the Institution in connection with that subject. Mr. Hall had worked engines at 115 lbs. pressure, the consumption of coal being 1·50 lb. per indicated HP. per hour. He had documents in his possession from a person who had seen the vessel running between Glasgow and Liverpool, which it continued to do for several months. A difficulty arose with the vessel, as difficulties had arisen with other ships treated in a similar way. A steam pressure of 115 lbs. had never been worked for any length of time successfully with marine engines. Where vessels had been built with steam pressed as high as that point, they had after a short period of work been compelled to fall back to a pressure of 75 or 80 lbs. Some doubt had been expressed with regard to the single engine. He had made many of those engines, not only for Mr. Alfred Holt but for Messrs. Holt of Liverpool, and others, and he could say that with a fly-wheel attached to the engine, on going into the engine-room of the ship one could see no difference between their working and the working of a double cylinder engine. Reference had been made to steam jacketing, but no allusion had been made to a much more important matter—that of reducing the steam to a low temperature. He believed that there was an immense loss by expanding steam at too low a temperature. The internal radiation or conduction with a low temperature involved an enormous loss, and it was better to work at a little higher temperature at the lower end of the stroke.

Mr. James Bailey, C.B., observed, through the Secretary, that the Author had suggested the use of higher pressures of steam as the means to obtain more economical results. From a return made to an order of the House of Lords in 1874, it appeared that the frequent renewal of marine boilers was an important item of expenditure, as well as a cause of great weakness in the practical strength of the British Navy. Amongst a long list of ships mentioned the "Pallas," first completed for sea in 1866, received new boilers in 1871, and the "Research," completed for sea in 1864, received new boilers in 1869; it would thus appear that the life of a marine boiler in the Navy was less than five years. The time occupied, and the expense attending the renewal of boilers, including the removal of old boilers and refitment of the ships to a working state, had not been given, but it must be a very heavy tax on the nation, independent of the ships being non-effective for considerable periods, and the strength of the Navy so much reduced.

During the present financial year, the building of new ships had been deferred to render the funds destined for ship-building available to re-boiler the iron-clads. What he wished to point out was, that with the improved system of steam engineering such as Mr. Perkins had initiated and matured these frequent renewals of boilers were unnecessary, and that the efficiency of the fleet, and its aggressive power, might be much augmented at a less cost than at present. This was accomplished by the use of engines working steam at a higher pressure, by boilers absolutely safe from explosion, and the two combined, by working the high-pressure steam more expansively, performed work on a much smaller consumption of fuel than at present. This system of engines and boilers possessed the following advantages, which increased both the efficiency and economy:—(1) The extremely small consumption of fuel, say 1 lb. of coal per HP. per hour. (2) The almost absolute safety of the boilers from explosion, brought about by the construction of tubes and the distribution of metal to secure strength in the position and form for performing the functions required in a boiler for containing high-pressure steam safely. (3) The duration of the boilers equal to that of the engines and ship they were applied to. (4) The disuse of all oil and grease for lubricating the interior wearing surfaces. (5) The reduction in the weight of the engines and boilers combined, as compared with those in use. In reviewing these features their great economy and industrial bearings would be apparent. (1) The consumption of fuel in steam vessels might be practically regarded as the index of their commercial value, and in ships of war as that of their aggressive power. In vessels of commerce, each ton of coal burnt should be valued as the cost of the same ton plus the loss of so much paying cargo as the ton occupies; whilst in vessels of war, to the cost of the coal may be added the gradual disablement of the vessel as the supply of fuel is exhausted. The reduction of the consumption of fuel in steamers by one-half, still maintaining the same actual HP., meant also that they could do a double journey, or keep the sea twice as long; this latter advantage was of vital importance to ships of war, and was of no slight importance to the mercantile fleet now trading to India, and other distant places. The best-constructed compound engines used, say, 2 lbs. of coal per HP., whilst Mr. Perkins's system used only 1 lb. It might be observed that the reduction in the consumption of fuel brought a corresponding reduction in the staff of stokers and coal-trimmers, and by means of the boilers being encased with a non-conducting

material, the engine room and stoke-hole were maintained at a lower temperature—a matter of practical importance in the Red Sea and other tropical latitudes. (2) He had been fortunate enough to see a Perkins boiler burst from being allowed to get short of water, whilst the high-pressure steam (500 lbs. per square inch) was on, with no worse result than the escape of the steam up the funnel. For vessels of war, liable to receive a shot in their boilers during an engagement, this quality was very valuable; and in case of damage, as the parts were interchangeable, repairs might be effected afloat, or at the nearest port or naval reserve of stores. (3) The boilers were charged with rain or drinking water, and this, after being converted and used as steam, was recondensed and reused. If all the joints and valves were theoretically perfect, the same water would last for ever, as it was only the loss caused by these imperfections which had to be made up. In practical work, the quantity required had been found so small as to be easily provided for. This water being comparatively free from solid matter, and small in quantity, created no deposit or crust inside the boilers, they never became burnt, and the wear was so slow and gradual, that one, when taken to pieces, after twelve or thirteen years' constant work, by the Admiralty Boiler Committee, showed no appreciable sign of decay. By this system, the boilers could be made equally lasting with the engines and ship. This feature alone deserved attention, especially in the working of sea-going vessels, the boilers of which were so frequently renewed at great cost, entailing lengthy demurrage in the case of the merchant navy, and for the time rendering ships non-effective, and occasioning loss of strength to the nation in the cases of ships of war. (4) One of the requirements to overcome the friction in the cylinders, when dealing with high-pressure steam, was attained by the discovery of the Perkins patent piston metal. At even moderately high pressures it was found that the cylinders were cut, and that the wearing surfaces of the valves and slide faces were kept true with difficulty. These drawbacks had been thoroughly mastered by the new metal, bringing with it the further benefit of requiring no artificial lubricant. The cost of the oil and grease was thus saved, and the frequent inconveniences caused by their residues in cylinders, pumps, and condensers were thus avoided. It might be justly stated that, by the use of this metal, one of the most material hindrances in the way of the successful application of steam at higher pressures than heretofore, had been overcome. (5) The cost of making engines on Mr. Perkins's system did not, he believed, exceed that of any other well-manufactured engine,

actual working power being taken as the criterion; and the weight and space required by the engine and boiler were less than of other engines in general use.

Mr. WALTER BROCK, through the Secretary, observed that, of all the points worthy of discussion, suggested by the Paper, by far the most important, in his opinion, was the issue raised as to the effect of "Governmental interference with steamships on the plea of public safety." He regretted, therefore, the remarks made by the President, deprecating the discussion of the action of the Board of Trade in this matter. This question was of vital importance to the steam shipping interest of the country. It was believed that Government interference, while in some respects beneficial, had in the main, and especially in its recent developments, been prejudicial and obstructive. Hence, it would appear to be in the highest degree desirable that this subject should meet with the fullest consideration and discussion from the members of the Institution. Attention had been specially called to what Mr. Traill referred to as "the book," in regard to which the Author justly remarked that it "will repay perusal and be found not unamusing." This "Book of Instructions to Surveyors of Ships," in the part devoted to steam machinery, contained detail rules in accordance with which certain parts of the said machinery must be constructed. Apart altogether from the question whether these rules were correct or not (and that they were not he, in conjunction with others, had endeavoured to show in another place), it must be evident that if the Board of Trade persisted in their present policy, it must necessarily lead to a large and indefinite multiplication of the rules, so as to embrace, ultimately, all details of steam machinery on board ship. Dealing, as they did at present, with only a few out of the many details of machinery, their position was capricious and illogical, because no sufficient reason could be assigned why certain parts should be specially legislated for to the exclusion of others equally important. The necessary outcome, therefore, of a persistence in the present line of action must be to make a Government department the responsible designer of the engines and boilers of the mercantile marine. The mere prospect of such a possibility, with its attendant consequences, appeared to him amply sufficient to justify the Author's suggestion that the Institution would add to the services it had rendered to engineering progress by protesting. Mr. Traill had given what he called facts as to the bursting of two boilers by hydraulic pressure; but, as far as he recollected, the only inference which he drew from them was a corroboration of the rule

given in the "Book of Instructions" for calculating the strength of boilers. Mr. Traill seemed to have overlooked one aspect of these experiments, which he took to be the most important, viz., that they showed what was the actual margin of safety possessed by these boilers during the time they were at work. He believed he was acquainted with all the particulars of one of the cases cited by Mr. Traill, and what was said above at least applied to it. It was the case of the boiler which burst at a pressure of 230 lbs. per square inch. This boiler had been constructed for a working pressure of 60 lbs., and, as a matter of fact, worked for some six or more years at that pressure. It would be admitted by all engineers acquainted with that experiment, that the boiler was not in any way weakened by corrosion, and that, in fact, if it had been subjected to a pressure of 230 lbs. per square inch when new it would have burst then. The conclusion from this was that here, at all events, was one example of a boiler working with perfect safety for a number of years with a factor of safety less than 4. The Board of Trade required a nominal factor of safety of 7 and upwards for boilers as usually constructed. The "Book of Instructions," however, assumed a strength of iron considerably in excess of what was usually found in practice, and it was probable, therefore, that the real factor of safety of boilers constructed according to the rules was not more than from 6 to 6½. It was submitted that such a factor of safety was unnecessarily high, and might be considerably reduced, with great advantage. It would then become possible, with such a modified factor, and the use of the superior steel now to be obtained, to employ much higher pressures, and that with perfect safety, even in boilers of the present type. A curious illustration of the illogical position of the Board of Trade was to be found in a consideration of the elaborate instructions given for the construction of new boilers, as contrasted with the absence of any attempt to guide surveyors in the much more difficult question of the treatment of boilers that had been years at work, and as to the pressure to be allowed for them. In fact, the Book of Instructions, in regard to this very important question, merely remarked that, "In the case of old boilers, the surveyors must use their own judgment as to the necessary pressure to be applied." Now it appeared to him that the Board of Trade must either legislate on this matter, or leave it, as at present, to the discretion of the surveyors, who, if competent to deal satisfactorily with this important question, could surely be trusted in all other matters of a survey. He was aware that an objection had been

raised to leaving a survey in the hands of a surveyor, without detailed instructions for his guidance, because it would be likely to lead to a non-uniformity of practice at different ports. It appeared to him that this objection was of little consequence, because, with a competent staff of surveyors, it might very well be made a rule that a vessel passed originally by one surveyor should not, in matters of design and arrangement, be amenable to survey by another, but that the subject-matter of all other surveys should be confined to the effects of tear and wear on the material. He believed also that much trouble and annoyance might be avoided as to boilers by abandoning all rules and trusting entirely to a hydraulic test. It was submitted that, if a boiler stood a certain hydraulic pressure satisfactorily, it should be accepted as evidence that it was capable of working at one-half that pressure for twelve months, and the surveyor should grant a declaration accordingly. The engineering profession of the country could certainly be trusted to construct machinery without being held in leading strings by the Board of Trade, and, as regarded boilers, all reasonable requirements as to public safety would be amply provided for by the periodical testing above referred to. This, at least, was his opinion, and he submitted it as a point on which the varied and extensive experience of members of the Institution would be most valuable. The whole subject of Government interference was a large one, and the full discussion of even one aspect of it was quite beyond the limits of a communication of this kind. He would only then, in conclusion, remark that there was a widely diffused feeling of dissatisfaction among engineers and shipowners in regard to their present relations with the Board of Trade, rendering as they did any attempt at progress, involving deviations from the beaten tract, exceedingly difficult, and there was an utter want of confidence in the professional advice under which this highly unsatisfactory state of matters has been produced and maintained.

Mr. E. De Rusett remarked, through the Secretary, that the Author had made a statement to the effect that the indicator as an instrument to find out faults was of considerable value; but that its results as a gauge of the propulsion imparted to a ship were often questionable. With these remarks he fully concurred, and would add, that by employing the indicated HP. as a divisor into the coal consumed per hour, a false impression might be conveyed of the comparative economy of engines, when applied for comparison with those of a different type, or where there was a great disparity in the relation of diameter of cylinders to stroke. That

this view was correct he would endeavour to show by reference to the following table of results:—

No. of Example.	Name of Vessel.	Type of Engines, all Direct Acting.	Dimensions of Cylinders.		Ratio of Stroke to Mean Diameter of Cylinder.	Trial Results.		
			Diameter.	Stroke.		Displacement.	Indicated HP.	Speed per Hour.
a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*
			Inches.	Inches.		Tons.		Knots.
1	Ceylon	Simple	72	36	0·500	2,983	2,054	13·340
2	„	4-cylinder compound	48 and 96	36	0·500	3,025	2,542	13·955
3	Poonah	Simple	76	39	0·513	3,156	2,550	13·853
4	„	2-cylinder compound	56 and 97	54	0·706	3,970	2,590	13·953
5	Indus.	2- „ „	56 and 97	48	0·627	4,440	2,368	13·670

By a simple analysis of this table it would be seen, firstly, in the results obtained by the "Ceylon's" former simple engines (1), as compared to the work done by her present four-cylinder compound engines (2). The latter type required 488 indicated HP. more than the former to drive an extra 42 tons displacement $\frac{6}{10}$ of a knot faster; but 170 indicated HP. would have been ample, other conditions being the same. Secondly, by comparing the power indicated by the simple direct-acting engines of the "Poonah" before lengthening (3), and that developed by the compound engines, after lengthening (4), the discrepancy was very marked. The power being only 40 HP. more in the latter trials, although there was an increase of 814 tons in displacement, and $\frac{1}{10}$ of a knot in speed. The indicated HP. to produce these results on the basis of those obtained with the simple engines would be about 3,036 or 446 more than that actually required on trial. Thirdly, in the instance afforded by the "Ceylon" (2), and "Indus" (5), the want of uniformity in indicated power was still more apparent. The two-cylindered compound engines of the "Indus," with 174 less indicated HP., drove 1,415 tons more displacement than did the "Ceylon's" four-cylinder compound engines, but at a reduced speed of nearly $\frac{3}{10}$ knot. Reducing these elements of displacement and speed to equal terms, the indicated power required to drive the "Indus's" displacement at "Ceylon's" speed would be 3,086 HP., or 718 more than actually sufficed. The Admiralty formula of $\frac{V^3 \times D^{\frac{2}{3}}}{I.\ HP.}$ had been employed

in each of the above calculations, as it was at present more generally accepted.

Similar instances of the unreliable value of indicated HP. as "a gauge of the propulsion imparted to a ship" were not by any means rare, and this he had observed nearly nine years ago, when investigating the comparative economy of simple and compound marine engines. He was then led to frame a formula $\frac{V^2 \times D^{\frac{2}{3}}}{C}$, when endeavouring to reduce the elements of speed and displacement to as nearly as possible the same terms. His observations extended in some instances over a series of years, so that the other elements, of weather, quality of coal, and the state of the ship's bottom, would be practically common to all, and so neutralised in such an investigation. V^2 had been adopted because the coal consumed per mile was taken as a divisor instead of indicated HP. He had ever since then adopted for this purpose the coal consumed either in lbs. per mile or tons per day; the power of V changing according to circumstances. In a Paper on lengthening the "Poonah," read by him before the Institution of Naval Architects during the present year, the formula used was $\frac{V\ 2{\cdot}3 \times D^{\frac{2}{3}}}{C}$, and where C = tons net coal consumed per day. The reason for changing the power of V^3 to $V^{2{\cdot}3}$ was there given.

The reasons for such discrepancies in indicated power might be looked for in the instrument employed, size and lead of indicator pipes, and also largely, he thought, in the varying ratio of stroke to diameter of cylinders. Examples of this might be observed in the table. Compare these ratios in Examples 3 and 4, also 2 and 5, column *f*, in each of which when the ratio of the stroke to the diameter of the cylinder approached more nearly to equality, the indicated HP. had produced a much higher propelling effect, as might be clearly seen by reference to the preceding analysis. These facts and deductions coincided with the Author's observations in advocating long-stroke engines, and in the condemnation of "cheese shaped" cylinders. He repeated that these objections to the use of the indicated power were only meant to apply where used as a means of comparison between engines of dissimilar type or those in which there was much disparity in the ratios of the stroke to the diameter of the cylinders.

He would now call attention to what the Author observed in reference to companies having postal subsidies. In refutation of his statement that "Government money was used to crush com-

petitors, and as a matter of fact did much to postpone all outside improvement in steam carriage at sea," besides other observations to the same effect, he might mention as an historic fact that the Peninsular and Oriental Company built the "Pasha," an iron paddle-wheel vessel, as early as 1843, or nine years prior to the date from which the Author commenced his review of the progress of steam shipping, and that this company had built and completed by July 1852 fifteen iron paddle and five iron screw steamers, and they had also other nine iron screw steamers building and fitting out by December of the same year. They had moreover increased their fleet by eight iron screw steamers by December 1853, and among these the far-famed "Himalaya." Of the entire fleet of this company to December 1852, comprising twenty-six ships in full work and twelve building or fitting out, there were:—

—	Completed.			Building.		Total.
	Dates.	No.	Tonnage.	No.	Tonnage.	
Wood paddle vessels	From 1836 to 1843	8	10,325	3	1,858	11
Iron „ „	„ 1845 „ 1850	13	14,997	..	..	13
„ screw. . .	„ 1851 „ 1852	5	4,293	9	17,777	14
Totals . . .	..	26	29,615	12	19,635	38

This list excluded two iron paddle-wheel vessels lost; one of which, as already stated, had been built in 1843. By these figures it would be seen that two of the three great changes of construction defined by the Author as having rendered possible the extension of steam shipping, viz., the screw and iron vessel, had received at the hands of a postal subsidised company, "that firm unhesitating acceptance which is a necessary prelude to general adoption;" and especially when it was known that this company had not laid down a single wooden vessel since 1843, except the three building in 1852, which were built of wood and copper-sheathed, simply because they were to be employed on a station where no graving docks were at that time available.

In the next place he would demonstrate the part subsidised companies had taken in the advancement of the third "great change," viz., the adoption of the compound engine. Contrary to the Author's assertion they had been among the first to adopt them and to extend their use. By reference to a list of compound engines kindly furnished him by Messrs. Randolph and Elder,

he noticed that that firm built forty-eight pairs of engines of this type from 1855 to November 1866, consisting of eighteen paddle and thirty screw engines. Of these the second and third pairs were for the Pacific Steam Navigation Company; and that the total collective nominal HP. amounted to 9,190, of which 6,620 or 72 per cent. were for subsidised companies, viz., the Pacific, African, and Panama and New Zealand lines. As regarded the four-cylinder type of compound engines alluded to by the Author as "an excellent engine," and as having been "exclusively employed in the boats of the White Star Line," the Peninsular and Oriental Company had adopted them in the "Mooltan" in March 1861, and she was followed by nine other vessels also fitted with this type of engine to April 1866, when they abandoned this form, and preference was given to the two-cylinder type, such as was now so satisfactorily employed in the propulsion of the largest steamers. At the present time the whole of their working fleet was propelled by compound engines.

With these facts it could not be said, that with all subsidised companies, "science, economy, thrift, all went for nothing, or that such companies have caused great waste, weakened steamboat enterprise as a whole, and left those who received them with fleets and habits unfitted for the race of open competition." The latter part of this quotation from the Paper might be answered by reference to the well-known immunity from losses at sea, both of ships, passengers, and mails, which had been enjoyed by at least two of the great companies—the Cunard and Peninsular and Oriental—the latter not having lost a vessel since the "Rangoon" in 1871, although their fleet have traversed more than 10,000,000 miles, in most intricate waters since that date; and at the present time the whole of their fleet employed in the Mail service, consisting of over 110,000 tons register, was constructed of iron, fitted with the compound engine and screw propeller.

Sir C. A. HARTLEY observed, through the Secretary, that having lived a great deal abroad for the last twenty-two years his attention, as a civil engineer, had naturally been frequently directed to the progress of steam shipping in foreign ports. His chief experience had been with the Black Sea ports, especially with the ports of the Lower Danube. With reference to the latter, he had prepared a note of the clearances of shipping from the Sulina Mouth in 1865, as compared with 1876. The year 1865 was a fair average one for the Danube trade, before the deepening operations of the European Commission of the Danube had been fully developed. In 1865, only one hundred and eighteen steamers

of all nations, of an aggregate of 31,545 registered tons, traded to the Danube. In 1876, six hundred and ninety-three steamers of all nations cleared from the Sulina Mouth, with an aggregate tonnage of 552,340. In 1865, the steamers, which only averaged 267 tons each, bore a proportion of but 7 per cent. of the total tonnage of the Lower Danube, which that year amounted to 410,684 tons. In 1876, the steamers, which averaged 800 tons each, bore a proportion of 74 per cent. of the total tonnage, which last year reached 748,363 tons. The increased tonnage and number of British steamers trading to the Danube, as compared with vessels of foreign nations, was remarkably exemplified by the following figures. In 1865, Great Britain stood only third on the tonnage list, her share, including both steamers and sailing vessels, being but 15 per cent. of the total tonnage; whereas in 1876, of the six hundred and ninety-three steamers which left the river, five hundred and twenty-one, of an aggregate of 445,000 tons, or 60 per cent. of the total trade, were British. Moreover, in the same year the number of English sailing vessels which traded to the Danube had dwindled down to twenty-six, having an aggregate of only 7,450 tons, or less than 2 per cent. of the tonnage of the English steamers. This striking example of the advance of steam navigation over sailing vessels seemed confirmatory of the Author's assertion, "that, broadly stated, British carriage by sea during the last quarter of a century has been transferred from sailing vessels to steamers." He considered, however, that the instance just quoted of the Danube trade did not prove the rule, and that, so long as the chief bulk of the ocean freight of the world continued, as at present, to be carried by sailing vessels, it could not with propriety be said that they had already been superseded by steamers in the carrying trade. Statistics showed that since 1862, although there had been a considerable reduction in the number of British sailing vessels engaged in the foreign trade (from seven thousand and ninety-five to five thousand three hundred and eighty-seven) there had been no diminution, but the contrary, in their total carrying capacity, which in 1862 was 2,993,696 tons, and in 1876 3,234,200 tons. On the other hand, the increase in the total carrying capacity of British steamers engaged in the foreign trade during the same period had been nearly 500 per cent.; but even with this immense increase—from five hundred and ten steamers with a tonnage of 328,310 in 1862 to one thousand four hundred and sixty-seven steamers with a tonnage of 1,489,264 in 1876—the aggregate tonnage of British foreign-going steamers was not yet equal to one-half that of

British sailing ships. It was worthy of remark, as an evidence of the greatly increased growth of late years in the carrying capacity of British vessels, sailing as well as steam, that whilst the average tonnage of steamers was only 600 in 1862, it had increased to 1,000 in 1876; and that whilst the average tonnage of sailing ships was only 422 in 1862, it had increased to 644 in 1876. Taking into account the total tonnage of British sailing vessels and steamers—river steamers excepted—engaged in both the foreign and home trade, it appeared by the following abstract from the Annual Parliamentary Navigation Returns that whilst the aggregate tonnage of steamers had increased 405 per cent. from 1862 to 1876, there had also been a slight increase in the same period in the tonnage of sailing vessels:—

Date.	Sailing Vessels engaged in the Foreign and Home Trade.		Steamers engaged in the Foreign and Home Trade.		Total.	
	Number.	Tonnage.	Number.	Tonnage.	Number.	Tonnage.
1862	19,059	4,011,501	1,033	461,793	20,092	4,473,294
1876	17,228	4,126,058	3,121	1,870,094	20,349	5,996,152

From Sir L. Mallet's "Statement of the Trade of British India for the five years 1871–72 to 1875–76," it appeared that, notwithstanding the immense impetus given to steam shipping by the opening of the Suez Canal, only 41 per cent. of the entire British trade with India was carried in 1876 by steam vessels. And yet, as the following statistics showed, the tonnage of steamers trading to and from India by the Suez Canal had increased threefold from 1871 to 1876:—

——	Entered.		Cleared.	
	Number.	Tons.	Number.	Tons.
1871–72	212	234,782	208	229,416
1872–73	259	318,300	273	308,524
1873–74	317	434,152	306	382,375
1874–75	413	575,892	409	558,076
1875–76	483	704,325	522	735,945

As an example of the value in a commercial point of view of the great Empire in the East, it might be mentioned that in 1876 the tonnage of British Indian sailing and steam ships trading to India

was 2,188,590, or 436 per cent. more than that of all foreign nations employed in the same trade.

He had been favoured by Sir John Stokes, K.C.B., Assoc. Inst. C.E., with the following statement (see next page) of the total traffic through the Suez Canal from its opening in 1869 to the 31st of December, 1876, distinguishing British steamers from steamers of other nations.

He would now briefly refer to the great preponderance of British ocean steam shipping to that of all other nations put together. Excluding river steamers, the commercial steam fleet of England was equal in round numbers to more than double that of the United States, to five times that of France and Germany combined, and to ten times that of Holland, Italy, Norway, and Denmark combined. With regard to the United States, Consul-General Archibald, of New York, reported to the Foreign Office that in 1860 nearly two-thirds of the foreign importations were brought in American ships, whereas during 1876, not more than one-fourth of the imports came in under the American flag. Mr. Archibald gave the following particulars relative to the number and tonnage of British vessels arriving at the port of New York in 1868 and 1876 :—

—	Sailing Ships.		Steamers.		Total.	
	Number.	Tonnage.	Number.	Tonnage.	Number.	Tonnage.
1868	1,690	543,256	312	702,865	2,002	1,246,121
1876	1,231	561,503	590	1,588,113	1,821	2,149,616

This comparative statement showed no diminution in the tonnage of sailing vessels, and a marked increase in the size of both sailing ships and steamers.

Although the Americans had hitherto surpassed all other nations in the building and equipment of fast and commodious river steamers, neither America nor any other nation had yet built steamships so well adapted for ocean navigation as those of Great Britain. Hence one great cause of the unquestioned supremacy of our mercantile steam marine. There were many other causes, however, which had led to this result, and among them might be mentioned: the vastness of our possessions in every quarter of the globe, free trade, an abundance of the requisite materials for the building and working of steamers, viz., iron and coal, the transport of the latter as cargo being also productive of profitable

SUEZ CANAL.

TRAFFIC FROM the DATE of OPENING to the 31st of DECEMBER, 1876.

Year.	British.			Other Nationalities.			Totals.		
	Number of Ships.	Net Tonnage.	Gross Tonnage.	Number of Ships.	Net Tonnage.	Gross Tonnage.	Number of Ships.	Net Tonnage.	Gross Tonnage.
1869 (36 days).	9	6,286	8,980[1]	1	290	435	10	6,576	9,415
1870. . . .	314	289,234	433,851[1]	172	146,677	221,064[1]	486	435,911	654,915
1871. . . .	502	546,453	819,679[1]	203	215,014	322,521[1]	705	761,467	1,142,200
1872. . . .	761	835,490[1]	1,253,235	321	325,253[1]	491,246	1,082	1,160,743	1,744,481
1873. . . .	813	999,861[1]	1,499,791	360	367,906[1]	585,281	1,173	1,367,767	2,085,072
1874. . . .	898	1,198,330[1]	1,797,494	366	433,320[1]	626,178	1,264	1,631,650	2,423,672
1875. . . .	1,061	1,454,258[1]	2,181,387	433	555,726[1]	759,321	1,494	2,009,984	2,940,708
1876. . . .	1,090	1,579,572	2,343,523	367	517,199	728,584	1,457	2,096,771	3,072,107

[1] Approximate.

outward freights; and last, not least, the advantage of having shipowners who knew the value of time, and ship captains whose energy, pluck, and seamanlike qualities so admirably fitted them, as a rule, for the important posts they held. The latter point was well sustained and corroborated in a communication which had been recently forwarded to the Foreign Office by Consul Clipperton, of Nantes.

In 1876, the total registered number and tonnage of all sailing and steam vessels belonging to the British empire were thirty-two thousand three hundred and seventeen sailing vessels, of 5,814,276 tons, and five thousand three hundred and sixty-three steamers of 2,150,302 tons, or together thirty-seven thousand six hundred and eighty vessels of 7,964,578 tons. In this return all the British possessions were included, and thirteen thousand five hundred and twenty-eight sailing vessels, of 404,664 tons, and seventeen hundred and sixty-one steamers, of 38,815 tons. Between 1872 and 1876 there had been an increase of 241,086 tons in the tonnage of sailing vessels, and of 509,663 tons in the tonnage of steamers. The estimated number of the crews (exclusive of captains) for all registered vessels belonging to the British empire in 1876 was 348,959.

But to return to the Black Sea ports. The total clearances of vessels of all nations from the Russian ports of the Black Sea and Sea of Azov, per year, during the three years ending 1876, were about 1,500,000 tons, of which 30 per cent. were British. He had not been able to ascertain the proportion of steamers as compared with sailing vessels, but her Majesty's Consuls of the Black Sea and Azov ports were of opinion that steamships continued to gain ascendency over sailing vessels. He believed that this ascendency would be still more marked as the deepening operations, undertaken by the Russians of late years in their Black Sea and Azov harbours, became more fully developed, especially after the deepening, which was completed only last year, of 5 feet, viz., from 13 feet to 18 feet, over a channel 250 feet wide, through the shoals of the Straits of Kertch from sea to sea.

The remarkable increase in the tonnage of steamships trading to the Danube was principally due to the deepening of the lower part of the river and of one of its mouths; and a consideration of this fact led him to conclude that, in addition to the three elements which the Author had represented as being the cause of the great progress of steam shipping up to this time, viz., the screw propeller, the iron vessel, and the compound engine, there was yet another element of value to be taken into account

—that of the increased depth of water which had been obtained during the last quarter of a century in harbours and rivers at home and abroad; for, as the Author had already observed, to work properly and to compete successfully with sailing vessels, steamers must have great depth of hold; consequently, they require a great depth of water in which to float. In this department of improvement hydrotechnical engineers had still a wide field of usefulness before them, no whit inferior in importance, he held, to the work which had yet to be accomplished by the great mechanical engineers of the day, whose chief aim was how to improve to the utmost possible extent the economical working of our commercial steam fleet present and to come.

With regard to the practical working of the Board of Trade regulations abroad, he had only to remark that the result of his personal observations, as far as the Black Sea ports were concerned, was that the working of the Merchant Shipping Act of 1875 had undoubtedly checked in a great measure the overloading of steamers and the bad stowage of grain; practices which previous to the passing of the said Act had been so perilous to human life, and so injurious to the best interests of trade.

It was stated by the Author "that the one who had almost alone benefited by the change was the consumer." Now he had the conviction that the whole of the civilised world had gained by the change, *i.e.* the late rapid strides of steam navigation, excepting perhaps a few unfortunate owners of sailing vessels, who might have been swamped from time to time by their powerful iron and steam competitors for the trade of the seas. It could not be supposed that steamship owners could always be gainers, when their steamers, after (as was too often the case) an outward-bound voyage in ballast only, actually carried cargo at times over thousands of miles at a rate of less than $\frac{1}{12}d.$ per ton per mile; yet even grain was carried at this low rate from the Black Sea ports to England, when freights fell, as they did in July 1876 for instance, from the Danube to England, to 4*s.* 6*d.* per quarter. There were seasons, however, when they reached, as in November following, 9*s.* 3*d.* per quarter, and at such a rate the profit must be great. His own experience was that owners of steamers, as a body, had been as fortunate on the whole in their speculations as their brother capitalists, who had invested their money in apparently less risky undertakings. The chief result of the rapid growth of the transport of goods over sea by steam power had undoubtedly been to lower the rate of freight from port to port; and producers, therefore, whether they lived on the banks

of the Ganges, the Mississippi, the Danube, the Vistula, or on the shores of the great American lakes, participated largely in the benefit of such lowered rates; for the value of, say, a quarter of wheat at any of these localities was the price paid in the British markets, less the cost of transport. Thus producers abroad had been benefited as well as consumers at home by the great progress of steam shipping during the last quarter of a century; and its still greater development in the future would, he felt sure, continue to prove a blessing to all mankind.

Mr. Douglas Hebson observed, through the Secretary, that while he concurred with the Author, who had himself done so much towards it, in what he had said of the progress of steam shipping during the last quarter of a century, he did not quite agree with him that the introduction of the compound engine had done more than the screw propeller or iron ship. The economy in fuel of late years had been due chiefly to the use of higher pressures of steam, and the Author himself seemed to think that it was not impossible that the single cylinder might yet be preferred. Theoretically, there was no doubt that the steam could be used economically in one cylinder as well as in the compound. However, the compound engines of the present day were thoroughly efficient, and did not involve any such complexity as the name suggested.

The Author had referred to the good service rendered by Mr. Elder in the introduction of the compound engine for steamships in this country. It might be interesting to the Institution to learn that Messrs. Alexander, of Barcelona, fitted a steamer with compound engines in Spain in the year 1854, and that they had continued to make these engines ever since. He had had under his care here four steamers fitted by them with compound engines of very good construction, entirely of their own design and manufacture.

In his opinion, by far the most important part of the Paper was that which referred to the action of the Board of Trade in connection with steam shipping. But for this, he should take a much more hopeful view of further progress in the future than the Author did; but when he remembered that in such a simple matter as the use of spring-loaded safety valves for steamships, it required repeated applications by different persons, extending over a period of from ten to fifteen years, before their permission could be obtained to use them instead of weights, which were unsuitable when a ship was rolling at sea, he felt apprehensive that other countries would take the lead in the race of improvement. He had before him a copy of the Board of Trade

instructions to surveyors, and he could not too strongly support the Author's wish that the Institution should take an active interest in the matter.

None but those who had experienced it could have any idea of the minute and injudicious extent to which steamship owners and engineers were controlled by the Board of Trade.

Mr. MACKENZIE remarked, through the Secretary, that, in his opinion, the rapid decay of boilers, when used with the distilled water from surface condensers, was probably to a considerable degree due to slow galvanic action going on between the boilers and the brass tubes generally used in surface condensers, which action would be kept up by the constant circulation of steam and feed-water between the two. He had recently seen a small wrought-iron pipe which had been corroded through, and required renewal in a comparatively short time. This pipe conveyed condensed water from a copper steam pipe. Similar wrought-iron pipes, taking condensed water from iron steam pipes connected to the same boilers showed no signs of rapid corrosion. There did not seem to be any reason why iron or steel tubes should not be used in surface condensers, as they answered perfectly under more unfavourable circumstances in boilers used with salt water. The Perkins engine had iron tubes in the surface condensers, and to these was probably due a part of the durability of the boilers which had been noticed by Admiral Selwyn.

Mr. F. C. MARSHALL remarked, through the Secretary, that to the compound engine, and its introduction to the mercantile marine, the Author attributed a large measure of the progress which steam shipping had made during the last quarter of a century; and principally because by its introduction the fuel burnt on board steamships had been reduced from the old standard of 4 lbs. and 5½ lbs., to 2 and 2½ lbs. per indicated HP., thus enabling the shipowner to undertake longer voyages, and so widen the field of his operations. The Author further proceeded to say that he did not look, nor hope, for more than a further reduction of 20 per cent. during the next twenty-five years, so bringing the consumption of steam engines on board ship to 1·8 lb. per indicated HP. It did not appear desirable, or a right thing, that such an expression of opinion, coming as it did from a most experienced marine engineer and large shipowner, should pass without remark. Marine engines had been made, and had afterwards worked on Mediterranean voyages on 1½ lb. of fuel per indicated HP., and on their trial trips realised the limit of 1·05 lb. per indicated HP. At this moment he knew of many steam vessels which were regularly

worked on long voyages on 1·7 to 1·75 lb. of fuel per indicated HP. It was in order that the statement of the ultimate result mentioned in the Paper as probably attainable in the future might not go forth as the unchallenged opinion of the members of the Institution, that he ventured to make these remarks. The fact named, that engines at sea had been worked, even on occasion, for hours together on a consumption of 1·05 lb. of fuel per indicated HP., and although they failed to maintain the modified result of 1·5 lb. for more than a few voyages, he held, should lead all persons interested in scientific and commercial progress to seek to make such result permanent. The difficulties in the cases he alluded to were, he believed, entirely of a practical or structural character, such as recent experiences had to some extent removed, and with the materials now available, which were not then, might be still further overcome. In consideration of these facts, it did not seem unreasonable to look for a 50 per cent. reduction, instead of the 20 per cent. on the present performances mentioned by the Author of the Paper. As the result of experience, he ventured to question the statement that there was even a speculative probability of the single-cylinder engine ever forcing aside the compound form. So long as it was found that increased economy lay in the direction of higher pressures, the conservation of the heat of the steam was of vital importance; and the wide range of temperature existing between the initial steam and the surfaces of cylinder, cover, and pistons, which had been exposed during the exhaust to the temperature of the condenser, must ever prove a hindrance to a return to a system involving such a positive and decided loss. The following was a statement showing the working of two steamers, identical in every respect, both started in the same year, and both engaged in similar trade; the one, the "King Coal," had two cylinders 38 inches in diameter, 30 inches length of stroke, and worked simple expansion with 40 lbs. steam; the other, the "Glenmanna," had cylinders 25 and 48 inches in diameter, 30 inches length of stroke, compound engines, with a steam pressure of 60 lbs. The statement showed the comparative running on the voyages to Hamburg and back, and the relative consumption of fuel and of water.

	"King Coal."	"Glenmanna."
Vessels:—		
Length	209 feet.	209·4 feet.
Breadth	28 „	28·2 „
Depth	14·5 „	14·4 „
Tonnage under deck .	647 tons.	650 tons.
Dead weight carried .	1,000 „	1,020 „

	"King Coal."	"Glenmanna."
Engines:—		
Nominal HP. . . .	90 HP.	90 HP.
Pressure	40 lbs.	60 lbs.
Diameter of cylinders .	38 inches.	25 and 48 inches.
Length of stroke . .	30 „	30 „
Boilers:—		
Length	10 feet 6 inches.	10 feet.
Diameter	13 „	11 feet 6 inches.
Heating surface . . .	1,974 square feet.	1,484 square feet.
Grate surface . . .	54 „ „	45 „ „
Propeller:—		
Diameter.	12 feet.	12 feet.
Pitch	14 feet mean.	14 feet mean.
Area	36 square feet.	36 square feet.

The average speed of "King Coal's" engines when loaded was 62 revolutions, developing 323 indicated HP. The average speed of "Glenmanna's" engines when loaded was 64 and 65 revolutions, indicating about 360 indicated HP. Both engines were by the same engineers, and the vessels by the same builders. The boilers of both vessels had been at work more than six years. His data were based as follows: In forty-four voyages to Hamburg and back, the "King Coal" consumed, on an average per voyage, 54 tons of coal; the "Glenmanna" 34 tons. He assumed that the quantity of water evaporated in both cases was eight times that of the coal used.

	"King Coal."	"Glenmanna."
Voyages per annum	44	44
Coals per voyage	54 tons.	34 tons.
„ „ annum	2,376 „	1,496 „
„ „ six years	14,256 „	8,976 „
Water evaporated per annum . .	19,008 „	11,968 „
„ „ „ six years . .	114,048 „	71,808 „

The saving in the amount of coal consumed in favour of the "Glenmanna" for the six years was £2,112, taking the value of coal at 8s. per ton. The "Glenmanna" would take nine years to use the same quantity of coal and water as had been used in the "King Coal" in six years. The average consumption of coal in the "King Coal" per day was 13½ tons, and in the "Glenmanna" 8½ tons. The last three voyages of the "Glenmanna" were done on 7 tons 11 cwt. 1 qr. 4 lbs. of coal per day. To his mind this showed that, even with the best management, the simple expansion engine could not be made to do the same work with equal economy, and therefore must give way to the compound engine.

As to the best form of compound engine the Author had not

stated his opinion, though the results of his experience on this point would be most valuable to the Institution. The modified form of Woolf engine, which he adopted for all his vessels, merited respect, if on no other ground than that he persistently adhered to it, even for vessels now building, and that he did so after many years' experience of its working on the longest voyages in the world. It occupied somewhat less space in the ship—what percentage of the "propelling power capacity," so called, he thus saved over the ordinary form it would be very interesting and useful to know—it had few working parts; he believed it was no lighter than the ordinary two-cylinder form, and by the aid of steam starting gear, fly-wheel, and a little management on the part of the "human factor" the Author mentioned, was readily started and reversed. But, judging from published statements, and a careful theoretical investigation of the working or behaviour of the steam under this system, it did not give so high economical results as the now common form of two cylinders of different diameters, with a receiver between, working on to cranks at right angles. In his recently published work, Mr. D. K. Clark, M. Inst. C.E.,[1] showed that with the ordinary form of Woolf engine, arranged in principle in the same manner as the Author and the constructors of the engines of the White Star line had adopted, there was a distinct loss of efficiency of from 10 per cent. to 12 per cent.; and that, with the best possible modification of the plan and the most careful management, this loss might be reduced to 5 per cent. over the ordinary form of compound engine. What he had called the ordinary, or receiver compound engine, was so well known as to need no description from him; and it had been so often recently discussed that it was unnecessary to go into its details. It sufficed to say that in its arrangements, whether in the two, three, or four-cylinder form, it afforded scope for large increase in pressures, large powers, long stroke, and great economical efficiency, inasmuch as by careful arrangement of cylinders a maximum of power might be got out of the heat of the steam, before bringing it into contact with the surfaces alternately exposed to the steam and condenser. In the four-cylinder form of engine, with others, he included those of the Woolf system adopted by Messrs. Imray in the White Star line, and which, by the very simple expedient of taking the exhaust of the high-pressure cylinder of one engine into the low-pressure cylinder of the other, instead of into that immediately

[1] *Vide* "A Manual of Rules, Tables, and Data for Mechanical Engineers." 8vo., London 1877, p. 855.

below it, as at present, all the advantages of the receiver plan could be obtained. He had not heard of this ever having been done, and never had an opportunity of doing it himself, but the losses before alluded to as incidental to the Woolf system proper might be avoided by so doing.

The comparative efficiency of the three descriptions of engine, which might be called the simple expansion, the receiver compound, and the Woolf compound, might be put down in terms of lbs. of steam per indicated HP. per hour as follows :—

Simple expansion in single cylinder	21 lbs.	to	30 lbs.	per	indicated	HP.
Receiver compound	15 „	„	18 „	„	„
Woolf	18 „	„	20 „	„	„

He knew many receiver compounds working at 16 and 17 lbs. per indicated HP. His experience of simple expansion engines gave 23 lbs. as the lowest and 33 lbs. as the highest weight of steam per indicated HP.—a large margin to be overcome before the single cylinder could displace the compound engine.

The Author complained of the rules of the Board of Trade, and more still of the action of its Surveyors. As a manufacturer, he could not indorse his complaints. It was true engineers were now subjected to an amount of inspection they did not like, and had to regulate their proportions by more defined rules than they sometimes thought were either wise or best. Still, he was old enough to remember the time when there was no other rule or guide as to the requirements of the Board of Trade than the whim and caprice of the Surveyor himself, and what was passed by him in one port was condemned the week after by his colleague in another. The rules were issued to remove the evils complained of, and now at least there was uniformity of requirement throughout the country. Again, it could not be denied that prior to the issue of rules, great laxity prevailed, even in the best establishments, in the arranging and proportion of plating, riveting, and staying of boilers, as well as in the workmanship connected with them. "Every man did that which was right in his own eyes," and it was to be feared that the "balance sheet" at the end of the year's work was too much considered in many cases, and led to bad design, bad material, and bad workmanship. The effect of the more careful supervision and enforcement of the rules had been to produce a greater equality of goodness in the workmanship and material. He was not going to say that the views enunciated in the rules were the best possible, nor that they were always necessary or wise; but he could in justice say this, that in every case

where an error had been pointed out, or a modification asked for, more in accordance with the just requirements of any special case, he had always found the officers in the out-ports ready to meet him as far as their powers would allow; and if these did not extend far enough, then an application to the officers in London, fairly and frankly put before them, had always been as fairly and frankly met. The Author was probably right in saying the tendency of the present system was to lead the Board gradually into the position of designer, and to a resistance to novelties and preference for stereotyped forms; but of late, complaint could not be raised that such had been the fact; novelties had been introduced after sufficient trial, and if, as in the case of steel for boilers and ships, the Board required careful tests and trials to be made before giving its official sanction to its use, it seemed to him that the history of steel manufacture in the past—as many builders could testify—both in the case of plates, bars, castings, and forgings, fully justified the caution the Board had exercised. This case of the use of steel was but one instance, many others could be given. The Board of Trade in all its departments was, to a large extent, what the public had made it, by its unceasing and often unreasoning demands; and if the outcome was not quite what shipowners liked, the way to remedy the evil was to grapple with it intelligently, and with due regard to all the interests concerned, and not by mere protesting or scolding on the part of any institution or body, however powerful or important.

Mr. R. E. Middleton observed, through the Secretary, that the discussion on the Paper recalled to his mind a small piece of personal experience illustrative of the steady running of single engines. In June 1871 he made a voyage from New Orleans to New York in the "Emily B. Soudar," an American screw steamer of about 1,000 tons. The engine was a single-cylinder one of the inverted vertical type, and the circulating pumps were worked by a separate horizontal engine. When in the Gulf Stream, off the coast of Florida, one of the tubes in the starboard boiler burst, and the engineers had to give all their attention to plugging it. There was a little sea on, and it was of importance that the engines should not be stopped; he therefore volunteered to take charge of the engines while the repairs were going on. It was impossible to drive the plug while there was any pressure in the boilers, but by watching the gauge in the engine-room closely, and by the help of a lamp held to the clearing cock, seeing that there was no pressure there, enough vapour was kept in the boiler to form a vacuum in the condensers,

and the single engine was worked for five hours without hitch or irregularity.

Mr. REDMAN observed, through the Secretary, that if during the last quarter of a century, carriage by sea had been transferred from sailing to steam vessels, and if profit and comfort were minimised in the process, it would be a sorry view for the British shipowner and traveller if this admitted of no explanation. This kind of broad assertion acted prejudicially; it was not new, and had been used by the opponents of harbour extensions, notably in the case of Dover. He had read a Paper on the 5th of May, 1875, before the Royal United Service Institution, on the Enclosure of Dover Bay,[1] in which he had shown the progressive increase of the commerce of Great Britain. It might be said that in 1850 the steam value as regarded tonnage carried was one-sixth of the whole only, but that it was now more than one-half, and this was exclusive of the Royal Navy, which, if included, would somewhat raise the steam value. When it was considered that in 1850 the aggregate foreign tonnage of the United Kingdon was fourteen millions, and that it was now fifty millions—in other words, that it had more than trebled and nearly quadrupled in twenty-seven years, and that there was a corresponding coasting increase—it was not extraordinary that wrecks, collisions, and fouling of lightships had been multiplied.

Mr. G. B. RENNIE remarked, through the Secretary, that the Author of the Paper had so much practice and experience with the working of what is now a large and powerful line of ocean steamers, that any remarks from him had great value to the owners as well as the constructors of steamships and their machinery. The Author treated the subject so fairly that one could not but agree in the most part with what he said. However, the "three changes of construction" mentioned by him seemed to deserve some further discussion in an engineering point of view. The "three changes of construction" mentioned by the Author as having revolutionised the sailing mercantile fleet of this country to one almost entirely propelled by steam, were: 1st, the screw propeller; 2nd, the iron ship; and 3rd, the compound engine. Of these, the screw propeller was practically the same as when adopted fifteen years previously to the time when the Paper took up the subject; namely, in the "Archimedes" merchant ship in 1839; and in the "Mermaid," afterwards named the "Dwarf," two years later, for naval service, as carried out by the late George and

[1] *Vide* Journal of the Royal United Service Institution, vol. xix., p. 665.

John Rennie: the former being a low speeded ship of 8½ miles per hour, and the latter a fast ship, with a speed of a little more than 12 miles per hour, which was faster than any paddle-wheel ship in the navy at that time. This ship had a length of 8 times her beam, which, according to the Author's statement, was very nearly the proportion now in favour, viz., 7¾ times the beam for the length. There was not, therefore, much to be said as far as the screw propeller was concerned, except to regret that the steamship owners did not see the advantages offered and adopt it at an earlier period than they did. 2nd. The iron construction of the hull of the ship had tended most materially to the development of screw propulsion. The screw propeller being applied to the extreme end of the ship, it was difficult to obtain, in a wood construction, sufficiently fine lines combined with the necessary rigidity to resist its constant working and vibration; and this was of perhaps more importance in merchant ships, which were usually worked at nearly full speed; whereas in naval ships it was only done on rare occasions. The iron hull, as usually constructed, was almost the same as in the earliest examples of iron ships, in which the late Mr. John Laird, of Birkenhead, amongst others, took a prominent part. Iron ships are now made considerably heavier than formerly, and in many cases, he was inclined to think, to their detriment. The system of fixed scantlings, in order to take a certain classification for insurance purposes, had rather tended to add material and weight to the ship more than its strength; the size and scantlings having more consideration than the manner of uniting its parts together and the quality of workmanship; this had much improved, however. The longitudinal construction of the framework of a ship had not found much favour with shipowners, but for lightness and strength had many advantages: it was commonly adopted in iron ships for naval purposes; and he believed he was right in saying that Mr. Scott Russell introduced this system, which had been afterwards carried out by him in the "Great Eastern." 3rd. The compound engine, as the Author stated, perhaps more than anything else, has given an impulse to the conversion of the sailing mercantile marine into fast-going steamers. In general terms it might be said, that the same power of engine, by its adoption, consumed half the amount of fuel than formerly was required, and enabled the ship to steam double the distance with the same coal bunk capacity. He submitted a comparative statement of fuel used in different kinds of engines, as mentioned in a Paper read by him at the Institution of Naval Architects in 1871.[1]

[1] *Vide* Transactions of the Institution of Naval Architects, vol. xii., p. 1.

Table 1. The type in ordinary use in merchant ships previously to the adoption of the compound engine was that marked No. 3,

TABLE 1.—COMPARATIVE CONSUMPTION of COAL.

Type of Engine.	Per HP. per Hour.	Tons per Diem.	Days and Hours Steaming with 240 Tons of Coal.
			Days. Hours.
1. Improved compound	2	43	5 14
2. Ordinary type, with surface condensers and super-heaters	3½	75	3 4
3. Ordinary injection	4½	97	2 11
4. High pressure	6	129	1 21

although there were some few engines in use of No. 2 type, and consumed even less than 3½ lbs. of coal per HP. per hour, as there stated, but they were exceptional cases; for example, a paddle-wheel engine of 300 indicated HP. on board a vessel called the "Dijleh," running on the Euphrates in 1866, between Bagdad and Bussorah, had an average consumption varying from 2·4 lbs. to 2·6 lbs. per indicated HP.; the steam in the boilers was only 25 lbs. pressure; the cut-off, by independent expansion, varied from ¼ to ⅓; surface condensers, superheater in the funnel being used, as well as the cylinders being steam jacketed. Now, as to steam jacketing, it would be interesting to the members of the Institution to know on what basis the Author arrived at the conclusion of this arrangement being practically of little use. It was quite contrary to the experience of many engineers. In order to satisfy himself as to its utility or not, he caused to be tried in his factory engine (and great care was taken both as to the indicated HP., coal, and other circumstances), for week by week alternately, with and without steam in the jackets round the cylinders. The results were shown in Table 2 (see next page); the columns marked A being those trials with steam let into the jackets, and those marked B without steam in the jacket; the average saving showed 31 per cent. in favour of A. It was essential, when steam surrounded the cylinder, that all the steam which had been condensed into water should be drawn off regularly, and this, no doubt, was more easily done on land than on board a sea-going ship; but he thought, with proper arrangements and ordinary care on the part of the engineer in charge, this was a difficulty to be overcome.

He was glad the Author of the Paper laid stress on simplicity

TABLE 2.

—	Number of Hours of Steaming.	Number of Revolutions.	Boiler-pressure.	Vacuum in Condenser.	Lbs. per HP. per Hour.	Indicated HP.
			lbs.	Inches.		
A	49	111·219	17·165	26·28	2·6	43·0
B	48	105·8	16·862	25·97	4·26	38·05
B	48	106·116	17·04	26·22	4·05	39·98
A	48	107·21	16·77	26·92	3·02	40·136
	Coal consumed 31 per cent. in favour of A.					
A	51	115·038	16·03	26·77	2·75	39·0
A	48	108·24	15·82	26·6	3·35	40·22
B	52·30	115·167	17·25	26·03	4·25	40·39
B	48	107·65	17·21	26·32	4·635	39·04
	Coal consumed 31·35 per cent. in favour of A.					

and accessibility of parts; for the tendency amongst shipowners had of late been for multiplying details and adding complication of parts. Many such appliances which might be serviceable on land or in smooth waters, were quite out of place when a ship was tossing about over Atlantic waves. The Author said that the owner of steamships preferred safety to science; but he expected the science he spoke of must be a misnomer. The Author also enlarged on the advantages of a long stroke and great velocity of piston travel; but, although inclined to agree with him generally, he did not when he characterised the short-stroke cylinders as "wasteful abortions;" he was induced to think he had some very inferior machine in view; for it so happened that the most economical engine he knew of had a short stroke of about $\frac{1}{3}$ of the diameter. The stroke of piston was 33 inches, the diameter of the large cylinder 100 inches. The speed of the piston was 530 feet per minute. The vessel which had these engines was her Majesty's ship "Briton," where the consumption was under 2 lbs. per indicated HP. This vessel was tried in 1870, and, he believed, at the time these engines were taken in hand there was no instance of an engine with a piston of 100 inches diameter making 96 revolutions per minute. He had often heard it said that the compound engine had the disadvantage of not being able to work with much variation in the speed or power of the engine. He had, therefore,

selected certain examples to show that the compound engine could work with a large variation of power. Table 3 showed three

TABLE 3.—INDICATED HP. at THREE VARIOUS SPEEDS.

Taken from cards of H.M.S. "Boadicea's" engines, 1876.

—	Number of Revolutions.	Steam in Boiler Room.	Steam in Engine Room.	Mean Vacuum in Condenser.	HP. of High-pressure Cylinder.	HP. of Low-pressure Cylinder.	Initial Pressure from Atmospheric Line HP. Cylinder.	Total HP.
1	10·5	..	..	27½	33·02	39·43	5·75 below	72·45
2	37·0	..	36	27	702·70	442·60	29·50above	1145·3
3	75·3	70	64	25½	2446·00	2194·00	66·00 „	5640·8

INDICATED HP. at THREE VARIOUS SPEEDS.

Taken from cards of H.M.S. "Bacchante's" engines, 1877.

1	30	..	40	28·0	360·0	254·4	8·3above	614·4
2	55	68	65	28·3	1838·0	1563·4	60·9 „	3401·4
3	73·36	70	65	26·7	2441·4	2990·9	61·8 „	5432·3

trials of the "Boadicea," with powers varying from 72 to 5,640 horses, or the greatest was $\frac{1}{78}$ of the least. The revolutions varying from 10½ to 75⅓ per minute. That of the "Bacchante" showed a variation of from 614 to 5,432 horses. The maximum power of each of these two engines was the largest, he believed, by nearly $\frac{1}{4}$ that had been obtained from any compound engine yet tried, acting on a single shaft and propeller, and was worthy of recording in the progress of steam navigation. Now, as to the future improvements, it seemed to him that, as the weight of the hull and machinery formed so important a consideration in a successful steamship, these permanent weights being as much as $\frac{1}{2}$ or $\frac{2}{3}$ the total weight of the ship, anything that could be done to diminish them, without making the vessel of a weaker construction, was most desirable. The better manufacture of steel, both in plates and bars, either by the Bessemer or Siemens process, offered opportunities for diminishing these weights by about $\frac{1}{4}$ or $\frac{1}{5}$. The only difficulty was how to preserve the surface of the steel; for he thought it was the experience of most engineers that steel did waste away much more rapidly than iron, especially in sea-water and a hot climate; good paint required renewing; and Portland cement, although a most effectual preservative, added to the weight. He

might mention the case of some iron and steel small vessels, which were sent to the eastern seas, where the steel hulls only lasted from three to four years, whereas the thin iron hulls lasted from twelve to fifteen years. The Admiralty Boiler Committee, he believed, had been making a variety of experiments on steel and iron, and he believed he was right in saying that a six months' trial showed that the average of the steel plates wasted away five times as fast as the ordinary iron, under certain circumstances; but whether similar circumstances existed with regard to the action of sea-water on the hull of a ship he was not prepared to say. As regarded the weight of the engines, the Whitworth metal came in well for making the shafts and other parts hollow, and consequently lighter. The "Bacchante" screw shafting had been so made; the outside diameter being the same as the "Boadicea's," but the metal was only 3 inches thick. As regarded the future economy of fuel, he was inclined to think that a good deal had yet to be done without increasing the boiler pressure by having the best machinery and workmanship, and by having the most efficient engineers, and paying them well, in order to make it worth while for careful and good mechanics to remain on board and look after the machinery.

Mr. F. J. ROWAN, through the Secretary, directed attention to some facts connected with the historical part of the subject dealt with in the Paper, which had not been noticed by the Author. They were an important feature in the history of the development of steam shipping, because, as Mr. Samuda had remarked, every bold stride from the beaten track deserved to be noticed, if not for its own value as regarded results achieved directly by it, at least for its effects in inspiring others with courage to advance. They had also an undoubted importance in view of that progress which was desired for the future by all who were interested in steam shipping or marine engineering, because they offered a practical demonstration that a large measure of that advancement had already been attained in numerous instances. In 1859, Mr. James Robert Napier, of Glasgow, communicated to one of the Glasgow newspapers some results, observed by him, of the working of the steamship "Thetis," then running regularly as a trading vessel between Glasgow and Liverpool. This vessel was built by the Messrs. Scott, of Greenock, the engines and boilers having been designed by his father, the late Mr. J. M. Rowan, and his partner, Mr. T. R. Horton. Her dimensions were about 190 feet length, 26½ feet breadth, and 15 feet depth. She was fitted with compound engines of about 240 indicated HP., with a surface condenser and

boilers for steam of 115 lbs. per square inch. The late Professor Rankine had reported that, on a trial carried out under his professional supervision, she had developed a mean of 226 HP. upon a consumption of 1·018 lb. of coal per HP. per hour, the coal having evaporated 11 times its weight of water, the boiler having had 9 square feet of heating surface per lb. of coal consumed per hour, and the theoretical evaporative power of the coal having been about 15½. Mr. Napier's letter, a copy of which followed, was valuable as being the record of the maintenance of similar good results in the face of all the practical difficulties of regular trading; and a consideration of the date at which this system of high-pressure steam with compound engines and surface condensers was practically demonstrated, justified a remark of his that his father and those associated with him not only anticipated Messrs. Randolph, Elder and Co., but actually did that which they either did not attempt or failed to do.

LETTER TO THE EDITOR OF THE "NORTH BRITISH DAILY MAIL."—THE EFFECTS OF RECENT IMPROVEMENTS IN STEAM NAVIGATION.

SIR,—To get regular, rapid, and cheap communication by sea with all parts of the world is a problem which has been but partially solved; and though engineers have for a long time been trying, it is but recently that the heavy cost involved in the fuel has been so greatly reduced as in most cases to render Government assistance unnecessary. Every decrease of fuel has increased the traffic, extended the limits of the voyage, and equalised its time. The screw propeller was for most voyages found to require considerably less fuel than the sidewheels, and a rapid increase of steam-propelled vessels followed its introduction. The longest voyages were tried with these vessels; but the fuel required for steaming the whole distance was so great, and so little space left for profitable freight, that this mode of performing it with existing vessels, except with Government assistance, was soon abandoned for that partial use of steam which has rendered the voyages of such vessels as the "Great Britain" and "Royal Charter" so successful. One vessel, however, is now being constructed of a size so great, that fuel for a voyage equal to the globe's circumference, to be performed at the rate of about 400 miles per day, can be put on board in Britain, and withal leave a large space for profitable freight. Mr. Scott Russell, the builder of this big ship, lately told the members of the British Association that it was the *smallest* vessel which could perform the voyage in the time, without coaling by the way, and which would have space sufficient for freight to make the undertaking profitable to its proprietors. Mr. Russell was probably right in what he stated at the time, but not now. The theory of the steam engine established by Watt has been laid aside, and one of heat engines, in general more in accordance with facts, is being gradually adopted. This theory has shown the direction in which a saving is to be found. The steam of ordinary engines has been heated, and a saving of from 15 to 30 per cent. of fuel obtained. New engines have been made, hotter steam used, and upwards of 70 per cent. of fuel has been saved. The most remarkable case of economy, from the use of hotter steam, with which I am acquainted, is that of the screw steamer "Thetis,"

reported by Dr. Rankine to have consumed 1 lb. of fuel for the horse power indicated. This vessel has been trading for months between Glasgow and Liverpool, and astonishing all with the small quantity of fuel required. I took a voyage lately to see if the results were maintained; and although I was unable to get a card from the engine to show its power, I got some results which may be trusted. The vessel is, I believe, 190 feet long, 26½ feet broad, and 15 feet deep; has a propeller 12 feet diameter and 23 feet pitch, and was loaded with about 300 tons weight of cargo to a draft of 11½ feet of water aft and 10 feet forward. The mean velocity during the voyage of 190 geographical miles was 8·78 miles per hour, with a head wind during more than two-thirds of it. The mean pressure on the boiler during the voyage was 82·60 lbs. above the atmosphere. The mean revolutions of the propeller shaft were 45½ per minute, and the fuel consumed during the voyage was at the rate of 3·45 cwts. per hour. This, I think, is from one-half to one-third of the fuel used by steam vessels in general; and as there was nothing in the appearance of the machinery to indicate a greater deterioration or falling off of efficiency, than in any machinery of the ordinary construction, I have no reason to suppose that it will not last as long as ordinary engines; and one reason for thinking it will last, and be efficient considerably longer, is the boiler being supplied with fresh instead of salt water. I believe that the saving is so great that the money received for the extra freight, and the fuel saved, will in many, if not in all cases, be more than twice the Government subsidy; so that if subsidised companies are profitable, a non-subsidised company, having machinery as economical as Mr. Rowan has introduced on board the "Thetis," will certainly be much more profitable.

JAS. R. NAPIER.

From that year until about 1862, eleven or twelve sets of similar machinery were fitted in steamers, principally by Messrs. the Greenock Foundry Company, and by Messrs. R. Stephenson and Company, of Newcastle-on-Tyne. In these the same elements in general were employed, but the steam pressure was increased to 120 lbs. per square inch. Alterations and modifications were introduced, in some cases with good and in others with bad effect; but the history of this advance in marine engineering differed in nothing from that of the combination of failures and successes which experience showed was inseparable from every such invention. A sufficient number of examples, however, endured years of work, and remained to prove the substantial correctness of the system; and within the last four years further examples working steam of 150 lbs. pressure, on a regular consumption at sea of 1½ lb. of coal per indicated HP. per hour, had been added. The Author had asserted that the consumption of the best specimens of compound engines with the ordinary boilers varied from 2 lbs. to 2½ lbs. of fuel per indicated HP. per hour, and that the greatest degree of economy he hoped for during the next twenty-five years was a reduction of 20 per cent. upon that amount. He ventured to say that there was no need to wait twenty-five years to see that hope fulfilled; for a consumption of 1¾ lb. to 2 lbs. had actually been

maintained in the past, and one of 1 lb. to 1½ lb. had already been demonstrated to be possible and practicable, by means of steam of 150 to 200 lbs. pressure efficiently generated and used.

The questions of boiler design and working entered largely into the consideration of this matter; and believing that the only proper road to success in these lay in the strict observance of scientific principles of natural action—often contravened with bad results in actual engineering work—he regretted the Author's remark, which seemed to place "the safe and the scientific" in opposition as though they were incompatible. He was persuaded that it was not so, and that in the long run engineers would in this matter, as already in others, reach their desired end by an intelligent submission to truth.

Mr. P. SAMSON remarked, through the Secretary, that the Author's charges against the Board of Trade were of so general a character that it was impossible to discuss them fully without opening up the whole question of Government interference with merchant shipping. An Act of Parliament had been in existence since 1854, which imposed on the Board of Trade the duty of carrying its provisions into effect by a staff of competent surveyors. By the provisions of the Act a shipowner was not allowed to embark passengers in a steam vessel unless she had been surveyed by, and declared fit for the service intended, by one of the surveyors appointed by the Board of Trade. There was also a clause in the same Act which provided for inquiries to be held by magistrates, assisted by assessors, in the event of serious accidents to hull or machinery. When a steam vessel had been surveyed under the Act, the surveyor, when satisfied that she was fit for the service intended, made a written declaration to that effect and handed it to the owner. The owner, in turn, forwarded it to the Board of Trade, who issued the statutory certificate. As the law stood at present, the surveyor must satisfy himself that the hull, machinery, and equipments were sufficient for the service intended, or leave himself open, in the event of an accident, to censure, or even to be tried for manslaughter where loss of life had taken place, if it were proved that he did not use due care or vigilance in surveying the vessel previous to granting his declaration. When once the declaration was granted it was the practice of these Courts to regard the shipowner as morally, if not legally, free from blame, even if the boilers should burst or the ship founder on her next voyage; and he thought no legal tribunal could, with justice, convict the shipowner for sending his vessel to sea if he held the declaration of a Government official that the ship was fit for the

service intended, unless it could be proved that the surveyor was intentionally deceived, and the owner knew of the defective condition of the vessel. The duties of the surveyor were therefore of a most onerous and responsible character, and his position, placed between the shipowners and the public, was of the most delicate kind. On the one hand, the shipowner, in his anxiety to make his vessel profitable, urged the surveyor to complete the survey in the shortest possible time; on the other hand, the public punished the surveyor if he granted his declaration without being fully satisfied with the safety of the ship. There were two ways of satisfying the surveyor: firstly, by personal inspection and calculation made by himself; and secondly, by personal inspection, coupled with calculation made with standard rules by some person in whom he had confidence. Both methods involved a large amount of tedious calculation, and were the first system attempted, at each survey the detention of the vessel while the calculations were being made would become a serious matter for the shipowner, and the present staff of surveyors would, at least, have to be trebled. The first system should be only resorted to when vessels were surveyed for the first time, and the second system at subsequent surveys. To carry out this system the surveyors must not only be satisfied with the honesty and ability of their brother surveyors, but they must be acquainted with, and satisfied that the rules adopted by each other were reliable and based on sound principles.

The accepted rules for regulating the scantling of the hulls of iron vessels were considered by most surveyors as sufficiently reliable, and these rules were generally used by them in the execution of their duty, and if added to the Book of Instructions would not make any material alteration in the present practice of the surveyors. Had the rules for boiler construction been in an equally satisfactory condition a few years ago, there would have been no necessity for the Board of Trade to issue the rules complained of by the Author, and a great amount of expense, thought, and labour would thereby have been saved to the officers who advised the Board on these matters. At the time these rules were published the steam pressure was rapidly increasing, and the workshop appliances were inadequate for manipulating the thick plates required for the shells of cylindrical boilers. It was also generally believed at that time by manufacturing engineers, that if a joint were double riveted its strength would be equal to 70 per cent. of the solid plate. These circumstances combined caused many double-riveted joints to be so malformed that the least section of plate or rivet was, to his own knowledge, in some cases reduced to

42 per cent. of the solid plate. Again, many engineers asserted that the plates they supplied had a tensile strength of 23 tons per square inch. These beliefs and statements were doubted by the Board of Trade, and it was resolved to make a few experiments to obtain information. The preliminary experiments conclusively proved that the strength of a double-riveted joint was not equal to 70 per cent. of the solid plate unless the quality of the iron was high, and the percentage of metal left between the rivet-holes was equal to 70 per cent. of the solid plate; and, further, that the rivet section must be equal to the net plate section if the plate was of medium quality. These experiments also showed that instead of boiler plates having a tensile strength of 23 tons per square inch, from 20 to 21 tons was nearer their value. The effects of punching different qualities of iron were also ascertained, and the injury found to be, in some cases, far in excess of what had been anticipated. These experiments had been followed by a most exhaustive series on riveted joints, the results of which corroborated the preliminary tests. The tests on joints would have been incomplete in themselves without experiments on actual boilers, as many engineers believe that crossing the joints of a cylindrical shell would add considerably to the strength of the longitudinal seams. This opinion appeared to have been shared to some extent by Sir William Fairbairn, as would be seen on referring to his most valuable work entitled "Useful Information for Engineers." The issuing of the Board of Trade rules had the effect of causing many engineers to investigate the subject of riveted seams, and two of the most influential manufacturing firms in the North, with a praiseworthy desire to gain experimental knowledge, burst two cylindrical marine boilers and a cylindrical superheater by hydraulic pressure to ascertain their strength. These experiments fully confirmed the rules in the Book of Instructions, which had been formed on the strength of riveted joints only, and corroborated in a remarkable degree the opinions held by Mr. Traill for many years previous to the Instructions being issued. A few years ago the Author appeared to hold very strong views on the subject of the strength of cylindrical shells of boilers, and went so far as to write a Paper on the subject. He asserted in the Paper and to the Board of Trade that the way to calculate the strength of the cylindrical shell of a boiler having the joints shifted, as in brickwork, was to draw a line from one end of the boiler to the other, through the joints and solid plate, and take the mean section of the plate in that line as the strength of the joint. Mr. Traill had asserted that by calculating the strength of the shell,

of a boiler by that method the results are from 50 to 85 per cent. per cwt. from the truth. It was worthy of remark that in each of the three experiments the plates of the outer shells were fractured through the rivet-holes of the longitudinal seams, thereby clearly proving that the cylindrical shells of modern marine boilers were the weakest portion. By calling the strength of the joints 70 per cent. of the solid plate, and taking the ascertained tensile strength of the material, the results were also very wide of the mark, as would be seen from the following figures:— Calculated bursting pressure of No. 1 boiler, about 348 lbs.; actual bursting pressure, 230 lbs. Calculated bursting pressure for No. 2 boiler, 284 lbs.; actual bursting pressure, 195 lbs. Calculated bursting pressure by Board of Trade rules for No. 1 and No. 2 boilers, 229·3 lbs. and 194·7 lbs. respectively, or less than 1 lb. from the actual bursting pressure in each case. These figures were sufficiently convincing to his mind that the Board of Trade did good service to all persons interested in the "progress of merchant shipping" by providing a rule for boiler shells which had no equal for accuracy. Sir William Fairbairn's rule for cylindrical furnaces was quite as unsatisfactory as the rules for cylindrical shells. The defects in Fairbairn's formula for flues were detected by the Board of Trade officers from a careful study of the results of the experiments recorded in the work called "Useful Information for Engineers," and the modified rule in the Book of Instructions was the result of that investigation. Within the last month two full-sized cylindrical furnaces had been made and tested to destruction by hydraulic pressure, to ascertain their strength to resist a crushing force. These experiments showed that the Board of Trade rule had a factor of safety of 6·2 in one case, and 5·5 in the other, and that the collapsing pressure by Fairbairn's rule, viz., $\frac{806 \cdot 300 \times T^2}{L \times D}$ = collapsing pressure, was in one case 68 per cent., and in the other 88 per cent. above the actual collapsing pressure, and if the formula $\frac{806 \cdot 300 \times T^{2 \cdot 19}}{L \times D}$ = collapsing pressure were used, the errors would be 47 per cent. and 56 per cent. respectively. The rule for flat plates supported by bolt stays was the result of combining the practice of the best makers throughout the country with the results obtained from testing experimental boxes stayed as in boiler-work. Previous to the date of these experiments, stays were in very many cases pitched by rule of thumb, and the plate between screwed stays without nuts was allowed as great a pressure as when the stays

were fitted with nuts, and the strength of the plate was supposed to vary as the square of its thickness. From these and subsequent experiments, made in one of Her Majesty's Dockyards, it was known that the usual thickness of plate supported by stays fitted with nuts was from 30 to 50 per cent. stronger than when the stay-ends were screwed and merely riveted over; and further, that the strength of the plate did not vary as the square of the thickness, as previously supposed. The calculated bursting pressure by the Board of Trade rule for the box tested in the Dockyard was only about 1 per cent. greater than the actual pressure, and the calculated bursting pressure for two other boxes tested a short time ago was not more than 3 per cent. from the actual bursting pressure. As the thickness of the experimental plates ranged from $\frac{3}{16}$ inch to $\frac{1}{2}$ inch, and the pitch of the stays from 8 inches to 15 inches, he contended that the rule gave results quite near enough for all practical purposes. The rule $\frac{C \times T^2}{P^2}$ = working pressure previously adopted by many engineers was to be found in standard books. If this rule were tested by the results of the experiment to which he had referred, it appeared somewhat absurd, for when the plates were of unequal thickness, and the pitch of the stays alike, the error was more than 20 per cent., and when the plates were of equal thickness and the pitch unequal, the error was no less than 35 per cent. The rules for safety-valve area in the Book of Instructions were not quite so satisfactory as he could wish, but it must be remembered that a committee of the Institution of Engineers and Shipbuilders of Scotland investigated this subject and published a most able report, in which they endeavoured to show that the area of safety valve required by the Board of Trade was too small for certain pressures, and on the other hand many engineers, chief of whom was the Author, had been writing pamphlets and endeavouring to prove that the same safety-valve area was excessively large. Under these circumstances the Board of Trade might be excused for adhering to the old practice, until engineers either agreed among themselves, or left the Board's officers to do what was best for all persons interested. From his own investigation of this important subject, he had no hesitation in stating that had the Author's advice been taken in the matter of safety-valve area and boiler construction, the lives of many men would have been placed in imminent danger. With regard to the remaining rules in the Instructions, he would merely state that they would bear as close investigation as the others, and give results equally satisfactory.

The Author contended that the regulations were not approved by well-informed engineers, and that this was proved by the dissatisfaction and irritation they had produced, and the remonstrances made by important associations. He did not think the Board of Trade would for a moment dispute the fact that some engineers had been displeased with the rules in the Instructions, but those engineers had been a small minority. Of this there was sufficient proof in the contents of a large number of letters received from manufacturing engineers, and others equally interested, who highly approved of the rules. The only remonstrance raised against the Instructions emanated from the manufacturing engineers of the Clyde district, but it was exceedingly laboured, and altogether unworthy of so talented a body. Besides, the reply they received to their objections appeared to have carried conviction, for they had been since that time silent.

The Author had drawn a comparison between the locomotive boiler and the marine boiler, which he considered altogether unfair, for the following reasons: locomotive boilers were, he believed, usually designed and made by locomotive superintendents, whose professional qualifications were generally of the highest order, and first cost was of little moment to a large company so long as a good boiler was secured. The designer had, besides, the purchasing of the plates and other material, and the workmen were under his control; and further, he had command of the purse and workshops of a powerful company. As workmen in railway locomotive works were not discharged to-day and taken back to-morrow, as was the case in many marine engineering works, they acquired a better knowledge of the ideas and wishes of the designer, and, on the whole, took a much greater interest in their duty. The boilers made by each railway company were of almost uniform type and dimensions, and the pressure carried was practically a constant. This circumstance rendered a mistake almost impossible, and the eye alone became so accustomed to the stereotyped form and dimensions, that it at once detected any departure from the usual practice. The designer of the boiler, having the control of its work, inspection, and repairs, could regulate its duty to suit the circumstances, and take it into the workshop for repairs as the nature of the defects might require; and further, the periodical inspections might be made as minute and searching as designer or circumstances demanded. The load on the safety valves of a locomotive boiler might be taken as the maximum pressure to which it was subjected, for as soon as the engine stopped, the generating power of the boiler was checked, and in a few minutes afterwards

it was practically nil. The cylindrical portion of a locomotive boiler, like the shell of the modern marine boiler, was, under ordinary circumstances, undoubtedly the weakest portion of the structure, but it was not subjected to the excessive racking forces from unequal expansion, and consequent leakage and corrosion like the latter, and explosions of locomotive boilers had not been attended with so great a loss of life as explosions of marine boilers in passenger vessels and in men-of-war with crowded stoke-holes; and he certainly thought that railway travellers sitting in a train behind a locomotive were less liable to injury from the explosion of the boiler, than the passengers of a river steamer crowded on the deck immediately over the boilers. The difficulties presented to the marine engineer were greater by far than were ever met by locomotive superintendents, for the steam pressure and form of boiler were ever varying to suit the requirements of the ship or engine. The result of this condition of things was that the eye never became so accustomed to the dimensions and distribution of the stays, plating, &c., as to enable even an experienced engineer to tell at once the strength of a boiler, without first making minute calculations; and further, the marine boiler was usually made by contract, which meant, in many cases, either low-class material or workmanship of an indifferent kind, and occasionally even both. The tools and other appliances in the works of some marine boiler makers were quite unsuitable for the purpose of turning out first-class boilers; and it was often the case that surveyors were unable to ascertain even the name of the maker of the boiler they were called upon to survey. The rivet-holes of marine boilers were, in a large number of cases, punched, and the rivet-holes drifted to make them fair, the effect of which was to damage the plates to an alarming extent, especially when the plates were thick and of poor quality. Again, some marine boilers were under steam for long periods, to meet the exigencies of the trade in which the vessel was placed, which prevented inspection or even necessary repairs being executed, until what at first might be a slight leak became a serious defect. Some marine boilers, too, had been found to suffer from excessive oxidation, and others from a deposit of lime on the parts exposed to the fire or hot gases. The natural draught of the marine boiler being independent of the exhaust of the engine, the steam was generated at the same rate with the engines at rest as when they were at work; hence in practice, when the engines were suddenly stopped the steam rose in the boiler about 10 per cent. above the loaded pressure. The straining force in boilers loaded to 100 lbs. was therefore 110 lbs.;

and further, it was seldom that every part of a boiler was sufficiently strong by the rules for the pressure required, and in such cases a range of 5 per cent. was usually allowed. The maximum straining force in many boilers passed by the Board of Trade was, therefore, 15 per cent. above the calculated load. As surveyors granted their declaration for periods of twelve months, they had to be guided, when fixing the working pressure of a boiler, not only by its condition at the time of inspection, but chiefly by its probable condition when the certificate expired; and it should be borne in mind that a passenger vessel, by the Act of Parliament, must be in a condition to make her last voyage with as much safety as the first; and that the surveyor who granted the declaration, unlike the locomotive superintendent, had practically no control whatever over the working, inspection, or repairs of the boiler. All those who had examined locomotive boilers laid aside as unfit for further use, and worn-out marine boilers as they were removed from ships, must have been impressed with the greater margin of safety still left in the former compared with the latter.

In reference to the factor of safety of modern marine boilers as made by recognised first-class makers, the experiments to which he had already referred furnished the means of ascertaining the actual factor of safety with some degree of accuracy, and he would here draw special attention to the important difference between a nominal and an actual factor. As the latest experiments showed that the cylindrical shell was the weakest part of a modern marine boiler, he would deal with that part only. The nominal factor of safety in the rules of the Board of Trade for the boilers and superheater experimented upon was 7; and if the plates had the tensile strength allowed in the formula, the actual factor of safety would also have been 7, but the plates became fractured between the rivet-holes with a mean stress of only 15·5 tons per square inch. To ascertain the actual factor of safety, it was merely necessary to reduce the nominal factor 7; as 15·5 tons were to the tensile strength allowed in the rule, which was 23 tons. In this way it was found that the factor was 4·7, assuming the greatest pressure in the boiler to be the load on the safety valves; but as the steam pressure rose, on an average, 10 per cent. above the loaded pressure, 10 per cent. had to be deducted to obtain the actual factor of safety, 4·3.

Sir William Fairbairn, in "Useful Information for Engineers," recommended in some parts a factor of 8, and in others a factor of 6; and Professor Rankine stated in his writings that boilers should be made to withstand a pressure six times greater than the

working pressure; while Dr. Anderson, in his work on the strength of material, stated that 7½ was not by any means too much for a new boiler, because corrosion and other causes soon reduced the original strength. Comparing the factors of safety recommended by those high authorities with the actual factor of safety possessed by high-class marine boilers passed by the Board of Trade, he thought that body could not with justice be charged with being wedded either to the opinions of others, or with demanding too much security for the travelling public.

The Author held that resistance to novelties might be expected and preference given to stereotyped form, but before accepting this as an axiom he would direct attention to the results of the past. During the time embraced by the Paper the Board of Trade had been intimately associated with merchant shipping, and looking to its past and present proportions, he thought all would admit that if the Board of Trade had not contributed to its "rise and progress" they had, at least, not put such obstacles in the way as would impede its growth. The past proved that the Board of Trade was not wedded to stereotype forms, for within the last twenty or thirty years the wooden passenger steamer had given place to the short iron steamer, the short iron steamer to iron vessels of excessive length to breadth; and at the present day vessels of steel were likely to supplant those made of iron. The improvements of the engines in the period stated had been quite as marked as those of the hull, for paddle engines had been superseded for ocean purposes by common screw engines of innumerable types; and again, common screw engines by the various forms of the compound screw and paddle engines. The surface condenser, centrifugal pumps, steam stearing gear, and numerous minor improvements had also been introduced. He would even say that there was not a single improvement of any importance which was not to be found in the passenger vessels surveyed by the officers of the Board of Trade. To assert that an undue resistance would be opposed to novelties was as unjust to the Board of Trade as it was uncharitable to the officers intrusted to carry out the wishes of the nation in reference to merchant shipping. It had been suggested that manufacturing engineers should have a voice in framing the rules on which the surveyors acted, but he feared few successful manufacturers would take the trouble or accept such a responsibility; and if successful manufacturing engineers were not to be obtained, he did not think it would be prudent, or for the benefit of those interested in merchant shipping, to employ engineers who had been unsuccessful in their profession. By the present arrange-

ment of the Board's advisers manufacturing engineers and shipbuilders of this country communicated information freely to the Board of Trade when requested, and the staff of surveyors, meeting as they did manufacturers of all grades and opinions in their district, were well able to supply useful information. Were only a few of the manufacturing engineers to be intrusted with the framing of rules for the department much jealousy would probably soon arise amongst them, for they, as a body, were very self-opinionated, and each considered his ideas superior to all others; and he thought it highly probable that the mutual good feeling now existing between the Board of Trade and the manufacturing engineers would suffer, if not be entirely destroyed.

Mr. RICHARD SENNETT stated, through the Secretary, that his views agreed generally with those so ably enunciated by the Author. The principal point on which he would submit a few remarks was, the third great change in construction, which the Author justly asserted had rendered possible the great extension of steam navigation during the last twenty-five years, viz., the compound engine; and he thought most steam-users would agree with Mr. Holt that the introduction, or more properly, the adaptation, of the compound engine for marine purposes had the chief share in bringing about the great increase of steam navigation during the past quarter of a century. There could be no doubt that, *cæteris paribus*, the higher the initial pressure of steam used, the greater would be the duty performed by a given expenditure of heat. For example, the quantity of heat required to generate 1 lb. of steam at a pressure of 14 atmospheres was only 1·04 times that necessary to generate it at a pressure of 1 atmosphere, the temperature of the feed-water in each case being 100° Fahrenheit. The work possible to be done by 1 lb. of steam at the higher pressure was, however, more than four times as great as that possible to be done by the steam at the lower pressure, the final pressure in each case being 1 atmosphere. The economy of high pressures being admitted, the problem was reduced to finding the engine most suitable for the use of high pressures. Theory and practice both tended to show that high pressures could only be safely and economically used in the compound engine.

The advantages of the compound marine engine might be thus summarised:—

1. Reduction of the maximum strains on the framing, shafting, and bearings, and consequent reduction of weight and cost.

2. Increased regularity of turning moment, and consequent increased efficiency of the propeller in the water.

3. More economical use of the steam in the cylinders, and consequent increase of power from a given expenditure of heat.

The first two points were almost self-evident, but on the third there appeared to be some difference of opinion, and it had been stated that the gain in economy of steam by the use of the compound engine, if any, was so slight that it was more than counterbalanced by the increased complexity and cost of repair. It was to this point principally that he wished to refer. First, as to the economy of steam; the compound engine was only the logical extension of James Watt's principle of keeping the steam cylinder and the condenser separate. The idea was evidently to keep the vessels in which the steam was used at as nearly a constant temperature as possible. In a single expansion cylinder the temperature during each stroke varied from the initial temperature of the steam to the temperature of the condenser, whilst in the compound engine this difference was divided into two or more stages, which much reduced the loss by liquefaction. This loss by liquefaction was an indirect loss, and acted by the reduction of the initial and increase of the final temperatures and pressures, by which the efficiency of the steam was reduced; and at each stroke a quantity of heat was expended in simply raising the temperature of the surface of the cylinder, the heat passing away to the condenser without performing any useful work. On account of liquefaction it was impossible to carry out a high effective rate of expansion in a single cylinder made of conducting materials such as were necessarily used at present. He need not enter into details to prove this, as these points were generally admitted. But some opponents of the compound system averred that this gain in economy was more than counterbalanced by the increased complexity and cost of repair. This, however, was not necessarily the case. In the first place, there need be no greater complexity in the compound engine; but, on the contrary, with the same pressures of steam and rates of expansion as in a single expansion engine, the simplicity of construction should be on the side of the compound engine, if properly designed. Expansion valves might in many cases be dispensed with in compound engines, for, by proper setting of the slide valves, the ordinary ratio of cylinders used would give an expansion of from five to eight times at full power without any additional gear, and any increased expansion required for reduced powers could easily be obtained by use of the link. For a single expansion engine working at the same rates of expansion, separate expansion gear suited for early cut off would of neces-

sity have to be used, and this of itself would introduce increased complexity.

The Author had spoken of the complexity and weight of castings required for the two-cylinder compound engine. This, however, was not necessary. At first it was considered essential that these engines should be fitted with a large receiver between the high and low-pressure cylinders, and as this was generally cast around the high-pressure cylinder, it made a heavy and complex casting. This idea had now been abandoned, and some of the most successful two-cylinder compound engines had been made without any receiver, the exhaust pipe leading from the high to the low pressure cylinder, and the steam passages, &c., containing quite sufficient space for the steam before entering the low-pressure cylinder; and this system had rendered the castings quite as simple and light as for single expansion engines. The difficulty of starting that had sometimes been experienced with these engines was not inherent to the system, but was more a matter of detail than of principle, and, as the Author mentioned, had never amounted to a serious objection in practice. He was of opinion that the two-cylinder compound engine, or in case of large powers, in which a single low-pressure cylinder would be unwieldy, its counterpart the three-cylinder compound engine with one high and two low-pressure cylinders, was much more likely to come into general use than the four-cylinder engine with two high and two low-pressure cylinders, as it was, on the whole, more convenient and durable, occupied less space and weight, and was less liable to derangement. The superiority of compound engines over simple engines would be more demonstrated as the engines became worn. When the slides and pistons began to leak the loss would be much greater in the simple than in the compound engine, in consequence of the greater ranges of pressure in the simple engine. The steam that leaked past the piston in a simple engine would go direct to the condenser without doing any useful work, whilst in the compound engine the steam leaking past the high-pressure piston would have a chance of doing work in the low-pressure cylinder before getting to the condenser. The almost universal adoption of compound engines by steam-ship owners must prove that the economy and efficiency resulting therefrom were a reality, and that the course taken had not been from caprice or fashion, as had sometimes been suggested. The results of the few instances in which simple engines with high pressures of steam and high rates of expansion had been tried, both in the royal and mercantile navies, had generally been unsatisfactory, and were not such as to

justify any extension of that system. If high pressures were to be used—and there was little doubt that the tendency was to increase rather than decrease the pressures employed—the compound engine was a necessity; and if properly designed, it should be simpler, lighter, cheaper, more efficient, and more durable than its single expansion rival.

He was sorry to find that the Author felt compelled to speak somewhat in condemnation of the steam jacket. Properly designed and used, it should tend to produce considerable economy, especially with high rates of expansion. It was not so essential with compound as with simple high expansion engines, but he believed it would be beneficial to either. It had been shown by many experiments that the saving from the use of the steam jacket varied from 10 to 20 per cent., according to the rate of expansion used. This would, however, depend to a great extent on the method in which the jacketing was carried out. Mr. Holt appeared to refer to the system in which the jacket and cylinder were cast in one, which would necessarily introduce complexity of casting, and generally a large portion of the cylinder would be unjacketed and exposed to the action of the exhaust steam. With the system now frequently adopted, of casting the working barrel of the cylinder as a separate liner, and bolting to the main casting, leaving a steam space all around it, there was no complexity, the cylinder was efficiently jacketed, and there was no doubt that much economy resulted from its use.

He must, in conclusion, take exception to the Author's distinction between the safe and the scientific. The truly scientific must be safe and must be simple. Where machinery was not safe and simple, it was certain that the so-called science had gone wrong. The principal aim of science should be to bring correct principles to bear on practical subjects, and as regarded marine engineering this should increase the simplicity, safety, and efficiency of the machinery used for propelling ships both of war and commerce.

Mr. W. Shute remarked, through the Secretary, that in his opinion the great importance of form in ships, with regard to their profitable employment, had been hardly sufficiently recognised, either by the Author of the Paper, or in the discussion; and that no allusion had been made to several other matters of importance connected with this subject. The total value of cargoes at any time at sea must now be hundreds of millions sterling; and the interest on this vast sum, amounting to tens of thousands of pounds per day, must be a loss to somebody, so long as the principal lay idle unnecessarily. Even though the merchant or shipper might

trade, or speculate, meanwhile with money borrowed on the security of these cargoes to arrive, nevertheless there must be certain saving, to the many parties interested, by bringing all cargoes to their market port as quickly as possible economically. With passenger traffic, speed was of yet greater and of increasing importance. If it proved possible to further shorten all voyages, economically, by even some small portion of their present duration, by improvements in the forms of vessels, as well as by improvements in their propelling machinery, it followed that more voyages could be made, and thus more profit earned in a given time; and also that fewer ships of a similar size would be needed for similar work than now. As already pointed out, there was a large fund ready, out of which to provide the necessary improvements for effecting these savings, and a sufficient promise of profit to induce attempts at driving improved cargo steamers in future at somewhat higher velocities than the 8 knots per hour, which now seemed the economical limit of speed for such vessels—for the quickest ships would naturally be preferred. Such increased speeds would probably be gained chiefly by improving the forms of ships, since improved shape meant decreased resistance of the water to the vessel, and a consequent saving of power and fuel, with increased space for profitable cargo; whereas increasing speed by increasing power usually meant more fuel consumed, and thus less space for cargo. And even where, owing to finer lines, space for cargo might be somewhat diminished, yet this would not necessarily cause loss of profit, as it would be fully compensated by the saving of power and fuel, and by the advantages which increased speed brought with it. With finer lined ships, coarser pitches of screws might be used; and though speed was always limited by increased resistance, yet a somewhat larger, if finer-lined ship, might be driven at the same speed as a smaller but worse formed ship, by an equal amount of power. Or if the displacement were the same in both types, then a higher speed might be attained by the better shaped ship, if it had equal power; or an equal speed attained by it with less power and fuel. The value of Mr. Scott Russell's wave lines seemed even now to be hardly enough appreciated and used in cargo steamers. By the use of steel it was now possible, in addition to using finer lines, to effect a further economy by the reduction in weight of hull, enabling an increased cargo to be carried safely. Also any future saving of power now lost from waste of fuel, or too low pressure of steam, or through the excessive friction of some parts and the arresting and reversing the momentum of other parts of the machinery, besides any saving of waste in the propeller, would

all tend, in well-shaped ships, to increased speed, at present impracticable or unremunerative in the existing types of vessels. Hardly any mention has been made of the many experiments tried in late years with varied types of ships; such as those of Mr. Winan's with cigar-shaped ships; nor of the experiments of Dr. Collis Browne with ship models having long submerged ends, similar to those used by Mr. Reed in the "Bessemer" Channel steamer originally, and also as rams in war-ships. Neither was much allusion made to Mr. Griffith's experiments with screw propellers working in tubes, open at their ends only, through or beneath a ship lengthways; nor to the water-jet system of propulsion—though all these would seem to deserve further trial and notice. The successful use of auxiliary power in connection with sail power in the Royal Navy had not been mentioned, nor the attempts a year or two since to utilise the rolling and pitching motions of sailing vessels as a source of power by compressing air, which was to be stored up for use in calms. The practicability of such economical expedients seemed worth discussing. Another matter not mentioned was the use of Mr. Penn's wood bearings for screw shafts, which, lubricated by water only, reduced the friction of those heavy and quick-moving parts of marine engines, which seemed almost unavoidable in full-powered steamers. Such an application of a current of water to keep down any frictional heating seemed specially suitable to the hollow steel shafts now coming into use, which could thus be cooled both from their insides and outsides. There would seem to be great difficulty as to what use to make in future of old-fashioned, though not worn-out steam ships and machinery, which had become both uneconomical to work, and difficult to dispose of. It often neither paid to alter them, nor to break them up as old metal, although this was usually their unsatisfactory ending. Some of these old ships, with machinery removed, might perhaps be used with advantage as floating barracks, or as sailors' homes and training-ships in sheltered ports or rivers.

Mr. W. H. WHITE, Assistant Constructor of the Navy, remarked, through the Secretary, that the Author had evidently approached the question more from the side of the marine engineer and shipowner than from that of the naval architect; and this fact affected both his observations on the past progress of steam shipping and its possible future. For example, in his remarks on the advantages of iron hulls, he said: "It has been possible to construct vessels of much greater displacement, in proportion to the power required for propelling them, than can be done in wood;" which was, to say the

least, an incomplete statement of the question. It was quite true that with iron hulls vessels had been built of greater speed, size, length, and proportion of length to breadth, than would have been possible with wooden ships; and it was an axiom in steamship construction that increase in size led to an economy of steam power, that economy being measured by the ratio of the expenditure of power to the commercially remunerative carrying power. Approximately, the conditions of practice for similar ships were that the expenditure of engine power varied about as the two-thirds power of the displacement, whereas the weight of hull and the carrying power varied nearly as the displacement: the speed in this comparison was supposed to be constant for all the similar ships compared. This rough statement would serve his present purpose, although it required several important corrections to make it conform accurately to the true general law of comparison. Take, for example, two cases from actual ships, one of 1,830 tons displacement, the other of 3,660 tons; each steaming nearly 13 knots: in the larger ship 2,400 HP. were required, in the smaller 1,600 HP. were expended. The larger ship had a cargo-carrying power of about 1,400 tons for a certain voyage, the smaller of about 600 tons for the same voyage. In other words, the increase in the size of the ship doubled the carrying power, but was accompanied by an addition of only 50 per cent. to the HP. Within certain limits, this economy of power was as realisable with wooden hulls as with iron; but the result depending on the difference between the two materials was that the process of enlargement could be safely carried farther with iron than with wood. With this enlargement, also, the iron ship could be made longer and finer than the wood, the resistance being diminished by the alteration of form, quite independently of absolute dimensions. Possibly this was the Author's meaning, but it was by no means clearly expressed.

Nor did he make any allusion to the fact that, in proportion to the displacement, the weight of hull was less in iron than in wooden ships, the carrying power being, of course, greater. Take two ships of equal size and identical form: give one a wooden hull and the other an iron hull, and the latter would be lighter than the other by about 10 per cent. of the entire displacement. In other words, as merchant ships were usually built, the iron-hulled ship would have a carrying power (excluding hull) of about 67 per cent. of the displacement, and the wooden ship of only about 57 per cent. For equal speeds, steaming capabilities, and coal endurance, equal weights of machinery and coals would have to be

taken in both cases; hence 10 per cent. of the displacement would be added to the remunerative cargo-carrying power by using iron, even in cases where the wooden hull might give sufficient strength. These facts were, he knew, well recognised by shipbuilders, but the Author confused them in a general statement, whereas it was necessary to distinguish between the effect of form, size, structural combinations, and the material of which the hull was built.

Had the Author named these separately, he could scarcely have failed to make reference to the probable effects upon steam navigation of the replacement of iron by steel hulls. This change was now very near, and it must largely influence the economical aspects of ocean steaming. For example, it was no exaggeration to suppose that a steel ship equal in strength to an iron ship could be built at least 20 or 25 per cent. lighter than the iron ship; that was to say, whereas in the iron ship about one-third of the total displacement would be required for hull, in the steel ship one-fourth would suffice, and the steel ship would gain upon the iron nearly as much as the latter would gain upon the wood. Hence there was every reason to hope that the Australian service and other long voyages would, by the use of steel hulls, be made commercially remunerative, even if there should be no further improvement in marine engines—which was a very improbable supposition. The iron ships at present running to Australia burned, say, about 1,600 to 2,000 tons of coal on the voyage out, in order to carry about 1,200 or 1,500 tons of dead-weight cargo; if steel hulls were used the dead-weight cargo might at once be enlarged by about 400 tons, without loss of speed or lengthening the time of passage. To effect a corresponding saving by means of economical consumption of fuel would need the average rate to be lowered from $2\frac{1}{4}$ lbs. per indicator HP. per hour to about $1\frac{3}{4}$ lb., or about 20 to 25 per cent. The Author despaired—perhaps unwisely—of doing more than reducing the rate of coal consumption 20 per cent. in the next twenty-five years; here he would find in the use of steel hulls an equivalent saving at once presented to him for the very longest voyages that had to be undertaken, where the economy of fuel was of the utmost importance. On shorter voyages the comparative gain by using steel hulls would be even more valuable. For example, a first class Atlantic steamer of 9,000 to 10,000 tons displacement would burn, say, 800 tons of coal with her present compound engines between New York and Queenstown. A saving of 20 per cent. on the rate of coal consumption would add 160 tons to the dead-weight carrying capacity; the use of a steel hull would add about 700 or 800 tons—five times as great as the former addition.

Lastly, he must draw attention to the fact that the Author took no account of possible savings in the weights of marine engines in proportion to their power. This was a serious omission; for there was every reason to expect that what had been done on a small scale by Mr. Thornycroft and others might be repeated on a larger scale. There surely could be no essential reason why, for engines up to say 400 HP., it was possible to get 1 HP. for about ½ cwt., whereas for ordinary engines the weight per HP. ranged from 3 to 4 cwt. Of course there were great difficulties in the way of passing from the torpedo launch type of engine, with its enormously rapid piston speed, to the engine suitable for driving the screw of a large ship; but he could see no reason why some progress, at least, could not be made in the direction of lightening marine engines without rendering them wanting in durability or efficiency. All that could be saved on engines, hull, or coal consumption, of course could be used up either in building smaller ships for a certain work, or in getting greater profits out of ships of a certain size and speed.

These criticisms on the Author's interesting Paper were not made in any unfriendly spirit, but simply to indicate points of omission, which when taken into consideration rendered it not unreasonable to anticipate continued progress in steam shipping.

Mr. Holt replied, through the Secretary, to the written observations made through the same medium, that several gentlemen founded exception to his statements as to the present consumption of fuel and his outlook for the future, on the fact that higher pressures of steam had already been used and were in practice, producing power for less coal than he had named. Notably, Mr. Perkins's interesting system had been referred to, and there were others also. But his intention had been to set forth, as far as he was able, the broad facts of the present position of steamers as presented to the eye of the non-scientific shipowner, or as accepted by the ordinary "laity." He was well aware that greater economies than those mentioned by him had been obtained, and he had been privy to some of the instances, and had, in fact, instances in his own vessels; but the class of machinery giving these results had not yet met with general acceptance, and might still not unjustly be described as in the experimental condition. In his statement of consumption of fuel, he invariably debited the engines with all the coals used in the ship, though aware that the galley and donkey boiler made away with some, and that coals taken abroad were generally of bad quality and deficient in weight. He felt that the best way to meet the statement, "that there was not even a speculative probability of the single cylinder ever forcing

aside the compound form," was to say that the combat between the two for superiority would probably, by the rough and ready shipowner, not be decided on the ground of coal consumption alone (though on that ground the experience of pumping engines was in favour of the single cylinder), but on the ground of lightness, durability, and simplicity, qualities which he thought would be considered almost as important as economy in the future, and were probably possessed in a superior degree by the single cylinder engine.

He regretted to have to recur to differences of opinion with the Board of Trade, but he could not leave unnoticed two points in Mr. Samson's statement of their case. One had reference to an effort made by him years ago to induce the Board to view the strength of the shell of a cylindrical boiler as a whole, attributing, when the joints were broken and the plates not too wide, a certain amount of support to the joint in one ring of a boiler to the fact of its lying in line with solid plates in the two adjacent rings. He thought it could hardly need proof that his contention contained a measure of truth; he would put a case on the old rule that "principles are best tested by their extremes." Suppose a boiler of, say $\frac{3}{4}$-inch plates, had one cylindrical ring 2 inches wide and no rivets in its joint, but lying between two ordinary rings, would that boiler possess no strength? According to the Board of Trade rules it would not, whereas, in reality, its strength would hardly be affected. He still held the opinion that, to view a cylindrical shell as a whole was the truest way of arriving at its strength, and that to judge of it merely by the strength of one joint was unfair. This was evidently not the case where the strength of a chain was that of its weakest link. The other point was where Mr. Samson said, "had Mr. Holt's advice been taken in the matter of safety-valve area and boiler construction the lives of many men would have been placed in imminent danger." With his advice on boiler construction he had already dealt. The only advice he could recollect having given on safety-valve area was when he suggested in 1871 the following rule: "To ascertain the square inches of safety-valve area. Multiply the grate-bar surface in square feet by a fraction, whose denominator is the proposed pressure in lbs. on the square inch, and whose numerator is always 18, but the area never to be required to exceed $\frac{1}{2}$ square inch to the foot of grate bar." If Mr. Samson doubted the sufficiency of that rule, he would be happy to make the experiment, bearing the cost if unsuccessful, if only the Board would adopt it if successful. His own opinion, much

strengthened since 1871, was that it erred on the side of giving unnecessary area. On the subject of safety valve areas he would try to draw a parallel with locomotive practice, because no one could doubt the efficiency and sufficiency of their valves. He had paid close attention to this somewhat difficult comparison, and he would give the results. A locomotive would, with about 17 square feet of grate bar, if kept at full stretch burn about 14 tons of coals in a day, and there was reason to believe evaporated about $\frac{1}{10}$ less water than an average marine boiler in proportion to the coal burnt. Therefore the quantity of steam produced by its boiler was about equal to that produced by a marine boiler having about 96 square feet of grate bar. The locomotive had about 14 square inches of safety valve, and the marine boiler would be required by the Board of Trade to have 48. It was argued, however, that the cessation of the steam blast diminished the production of steam and warranted small safety valves. But would this argument hold water? Was it not a constant occurrence that a locomotive urged to its utmost was nevertheless blowing off steam strongly, and in these circumstances liable to stoppage? If so, the entire yield of steam, at its utmost, must at once pass through the safety valves. Any way it would be highly imprudent to provide valves of less capacity. The steam-boat boiler, be it observed, being able to diminish its production as quickly and completely, if not as automatically, as the locomotive by opening doors and closing dampers. Besides, steam-boats had easing gear which was never fitted to locomotives. His deduction from the whole matter was that locomotive practice warranted a large diminution of area from the Board's rule. He entirely denied that any recommendation of his involved risk to human life; all were well within the bounds set by the safest practice outside the Board of Trade, and he would be pleased to have more detailed argument on the subject than was possible in the proceedings of this Institution.

Mr. R. V. J. KNIGHT observed, through the Secretary, that various opinions had been advanced as to the amount of strength required to insure safety in marine boilers. Mr. Gray had spoken of factors 8 and 6, and referred to the opinions expressed by Sir William Fairbairn and Professor Rankine. Mr. Traill insisted on the retention of the factor 6, and quoted two examples as proofs of the accuracy of the Board of Trade rules for marine boilers. The Author and other gentlemen were in favour of a much lower factor, more nearly approaching to locomotive practice, but every one who had joined in the discussion appeared to have taken it for

granted that all boilers made in accordance with the Board of Trade rules have factors not less than 6, that was, that they would not burst with less than six times their working pressures. The rules to which he referred were published by Pewtress and Co., Great Queen Street, London, 1875. From the results obtained from the experiments he was about to record, it would appear that the factor of safety for large boilers, with double riveted lap joints made in accordance with these rules, did not exceed 4, if an allowance of 15 per cent. was made for crossing the joints, or a factor of 3½ if no such allowance was made. The following experiments were made at his request in 1873, to ascertain the strength of some riveted joints; all the boiler-plates were of double best iron; all the holes were punched at 3 inches pitch, and all the rivets were closed by a hydraulic riveter, and the butt straps were double, each ⅝-inch thick.

	Lap A.		Lap B.		Butt C.	
Size of plates	Inches. 9 × 0·99	Inches. 9 × 0·99	Inches. 9 × 1	Inches. 9 × 1	Inches. 9 × 0·99	Inches. 9 × 0·94
Diameter of rivets	Inch. 1·07	Inch. 1·07	Inch. 1·2	Inch. 1·2	Inch. 1·2	Inch. 1·2
Number of rivets	6	6	6	6	12	12
Area of rivets	Sq. Inches. 5·39	Sq. Inches. 5·39	Sq. Ins. 6·78	Sq. Ins. 6·78	Sq. Inches. 6·78 × 2	Sq. Inches. 6·78 × 2
Area of remaining plate	5·78	5·78	5·4	5·4	5·34	5·34
Broke through rivet-holes with	Tons. 62·5	Tons. 60·5	Tons. 69·1	Tons. 71·4	Tons. 93·6	Tons. 93·5
Broke through rivet-holes per square inch with	10·73		13·01		17·5	
Ultimate strength of plate per square inch	19·55		23·2		19·35	

The rivets for the butt-joints C were much in excess of the usual proportion, but it was considered advisable to use the same punch and pitch as was used for the lap-joints B, so that the plates for both joints should be placed in the same condition to start with.

The Board of Trade based their calculations on an ultimate tensile strength of 23 tons per square inch for boiler plates, but this was much too high for thick plates. The Admiralty specified for 21 tons per square inch, but they tested the plates and rejected all that fell below this standard. By bringing the above experi-

ments to the Admiralty standard, the following results were obtained:—

——	Lap A.	Lap B.	Butt C.
Size of plate	Inches. 9 × 1	Inches. 9 × 1	Inches. 9 × 1
Diameter of rivets.	Inch. 1·07	Inch. 1·20	Inch. 1·20
Broke through rivet-holes with	Tons. 66·72	Tons. 63·58	Tons. 102·5
„ „ „ per square in. with	11·52	11·77	19·0
Ultimate strength of plate per square inch.	21	21	21

For boilers with butt joints C, the Board of Trade rules allowed a working pressure of 3·53 tons per square inch of area between the rivet-holes, therefore the factor would not be less than $\frac{19}{3\cdot53} = 5\cdot38$. For lap joints B they would allow a working pressure of 3·43 tons per square inch, therefore the factor would not be less than $\frac{11\cdot77}{3\cdot43} = 3\cdot43$. For lap joints A they would allow a working pressure of 3·43 tons per square inch, therefore the factor would not be less than $\frac{66\cdot7}{3\cdot43 \times 5\cdot39} = 3\cdot6$. In this case the area of the rivets was taken, as it was less than the net area of the plate. In the butt joint C, the strain was central, therefore the reduction of two tons per square inch was no doubt due to punching the holes.

In the lap joints A and B the strain was not central, which was principally the cause of a further reduction of 7¼ tons per square inch. This was a greater loss than might have been expected, but as the four experiments on lap joints agreed so closely, he thought there was no reason for doubt. The lap joints A and B were only 62 per cent. of the strength of the butt joints C, yet the majority of boilers were made with lap joints.

As he had previously stated, the factors of safety would not be less than 5·38 for butt joints C, 3·43 for lap joints B, and 3·6 for lap joints A; because some additional strength would be gained by crossing the joints. At present he was unable to state the gain from experiment, but he thought it would in no case be great. If the cylindrical shell plating of boilers was only subjected to tension in the same way as the bottom plating of a girder, the shell plating would derive the same advantage from crossing the

joints as the girder plating; but this was not the case. In the shell plating the tension was due to pressure acting on a curved surface; and it acted with the same pressure on the weak joint as it did on the strong plate. When the tension became greater than the strength of an unassisted joint, the joint began to bulge; in other words, it assumed a curve of less radius, by which it was still able to resist the pressure; but as the pressure increased so did the bulging, until the rivets were sheared or the plate torn through the rivet-holes. This occurred long before the solid plates, with which it is assisted on both sides, attained their ultimate resistance.

The following experiments were made to ascertain the strength of circular furnaces as usually constructed for marine boilers: two furnaces, 3 feet in diameter and 6 feet long, were built up in two lengths, one 4 feet long and one 2 feet long. Each length was made of one Lowmoor plate, the ends being connected by a single riveted joint, so arranged as to admit of a true circle being kept. The ends of the tubes were flanged, and connected by rivets to each other, and to a strong boiler shell in the usual way.

They were subjected to water pressure until the weakest tube collapsed, when, after it had been shored up, the experiment was continued until the following results were obtained:—

Thickness of Furnace Tubes	Inch. $\frac{1}{4}$	Inch. $\frac{1}{4}$	Inch. $\frac{3}{8}$	Inch. $\frac{3}{8}$
Length of „ „	Feet. 2	Feet. 4	Feet. 2	Feet. 4
Collapsing pressure per square inch . .	lbs. 235	lbs. 217	lbs. 468	lbs. 390
Working pressure, Board of Trade Rules	45½	27½	81	60
Factor of safety.	5·2	7·9	5·6	6·5

From this it would be seen that the Board of Trade rules for circular furnaces agreed as closely as could be expected with the experiments, and that their factor was 6 for water pressure; but when the crowns of the furnaces were partially covered with even a thin scale, and exposed to the action of a strong fire, the factor 6 would probably be reduced to a factor 4.

It would be seen that the 4 feet lengths were only from 10 to 15 per cent. weaker than the 2 feet lengths, yet he would strongly advise the use of strengthening rings, provided they were so constructed as not to encourage deposit. He had seen the crowns of overheated furnaces brought down to such an extent that had not

the strengthening rings retained their shape, fatal explosions must have taken place. The Board of Trade rules for boilers were inconsistent in many respects, and must be revised before they could command confidence. Their strongest boilers have factors of 6, and the weakest boilers had factors of 4.

If their weakest boilers were safe, their strongest boilers involved a waste of materials. He did not wish to raise a doubt on the strength of their weakest boilers, as such boilers only furnished additional proofs that an actual factor of 4 was a safe factor. Take a boiler containing 18 lbs. of water for each square foot of heating surface, and let steam be raised to 60 lbs. pressure. With good fires and no escape for the steam, in about seven minutes the pressure would be doubled, and in about nine more minutes the pressure would be quadrupled; but if the boiler contained only 9 lbs. of water per square foot of heating surface, the same pressures would be generated in about three and a half and four and a half minutes. Such a case could not be met by increased strength of boiler, but over pressure could be prevented by keeping the safety-valves in good working order. The Board of Trade would not pass any safety-valves unless they were capable of discharging all the steam the boilers could be forced to generate at a pressure not greater than 10 per cent. above the working pressure, for which they deserved the best thanks of the public. The weakening action due to unequal expansion, and also by overheating, cannot be overcome by increased thickness of the plates. Unequal expansion could be prevented by increased circulation when getting up steam; and overheating could be prevented by keeping the boilers clean and the water at its proper level. Against the weakening action of corrosion, extra material must be provided for some parts to a very slight extent, as for instance the horizontal seams of rivets in the cylindrical shell; and for other parts to a greater extent, as for instance the stays; but to what extent such extra material was provided, was as much a matter of durability as it was a matter of safety,

For new boilers the Board of Trade rules allowed a working strain of 5,000 lbs. per square inch of net stay area, the factor of safety being 10. A screwed stay $1\frac{1}{4}$ inch in diameter over the threads, was $1\frac{1}{16}$ inch in diameter at the bottom of the threads; and when reduced by corrosion to $\frac{13}{16}$ inch in diameter it would have a factor of 6. If then $\frac{1}{4}$ inch was a sufficient addition to the $\frac{13}{16}$ inch stay, surely $\frac{1}{4}$ inch should also be a sufficient addition to a $1\frac{5}{8}$ inch stay; but the Board of Trade rules assumed that, in a given time the reduction by corrosion would be in direct propor-

tion to the diameter of the stay and to the thickness of the plate, which was inconsistent with experience.

November 20 and 27, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The discussion upon Mr. HOLT'S Paper, "On the Progress of Steam Shipping," occupied both these evenings.

December 4, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

THE following Candidates were balloted for and duly elected:—WILLIAM FOX, JAMES NINIAN HILL, DAVID FRANCIS HOGARTH, JOHN GALE JOPP, THOMAS COLTIM KEEFER, JOHN HENRY LOWE, ALAN MACDOUGALL, WILLIAM MORTON, WILLIAM COLTON PARKER, WILLIAM FURNISS POTTER, and LOUIS SCHWENDLER, as Members; LAWFORD MACLEAN ACLAND, Stud. Inst. C.E., WILLIAM RICHARD ACTON, AMBROSE AWDRY, Lieut. R.E., ALFRED BACHE, B.A., ROBERT THOMAS OLLIVIER BARBENSON, MARTIN BLOXSOM, EDWARD HENRY BOLD, ROBERT WILLIAM BOURNE, JAMES EDWARD NEVILLE BOYDELL, GEORGE JAMES COTTOM BROOM, GEORGE VAUGHAN BROWN, Stud. Inst. C.E., THOMAS COMMON BROWN, ADOLFO GARCIA CABEZAS, ALFRED EDWARD CAREY, Stud. Inst. C.E., JOHN CARLINE, CHARLES FREDERIC CLOUGH, HENRY JAMES COLES, CORNELIUS CORNES, JAMES CROFTON, Col. R.E., MATTHEW CURRY, Jun., Stud. Inst. C.E., CHARLES EUGENE DE RANCE, FEDERICO EDUARDO DUBOC, Stud. Inst. C.E., HENRY EVAN GRIFFITH EVANS, Stud. Inst. C.E., HENRY SOMERSON FREEMAN, THOMAS LINDSAY GALLOWAY, JUSTINIANO AURELIO GALVEZ, Stud. Inst. C.E., ARTHUR CHARLES GOTTO, Stud. Inst. C.E., JOHN PURSER GRIFFITH, JOHN GREEN HALL, FREDERICK GEORGE HANKIN, Col. M.S.C., HENRY GRAHAM HARRIS, ALFRED HOPKINSON, JOHN HOPKINSON, M.A., D.Sc., HENRY HOWARD, ROBERT HIGGS INCH, ALFRED JOHN INGRAM, Stud. Inst. C.E., JAMES IRVINE, GEORGE JESSOP, Stud. Inst. C.E., WARWICK HUSON JOHNSON, THOMAS ISAAC LILLEY, FRANCIS GASCOIGNE LYNDE, DAVID MANUEL, HENRY ROBERT HOWELLS MARTIN, Stud. Inst. C.E., WILLIAM JOSHUA MASON, Stud. Inst. C.E., HENRY MERRYWEATHER, LEANDER MUNRO MILLER, BOSWELL PARKINSON MILSOM, Stud. Inst. C.E., OCTAVIO

OLAVEGOYA, Stud. Inst. C.E., ALFRED PERRY, WALTER PITT, CLEOPHAS WILLIAM RATLIFF, CHARLES LAWRENCE PEMBERTON ROBINSON, B.A., Stud. Inst. C.E., RALPH SADLER, Stud. Inst. C.E., CECIL SCOTT, Stud. Inst. C.E., ARTHUR EDMUND SHAW, JOHN WALLIS SHORES, Stud. Inst. C.E., GUY SMITH, JOHN MOTLEY SMITH, HENRY FRANCIS SNEYD-KYNNERSLEY, ROBINSON SOUTTAR, HENRY LEWIS SPINDLER, FREDERICK STAFFORD, ALEXANDER STARK, Stud. Inst. C.E., GEORGE ERNEST STEVENSON, GEORGE WILLIAM SUTCLIFFE, JAMES TAIT, Stud. Inst. C.E., WILLIAM UPTON TINNEY, THOMAS WILLIAM MATTHEWS TISDALE, WILLIAM BLOMEFIELD TRIPP, GEORGE EDWARD VINT, Stud. Inst. C.E., JAMES WILLIAM WARDLE, Stud. Inst. C.E., WILLIAM HENRY WARREN, CHARLES HENRY BILLINGHURST WHITWORTH, Stud. Inst. C.E., and WILLIAM BOOTH WOODHEAD, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred JOHN HENRY ABBEY, THOMAS AVELING, ROBERT BALLARD, JOHN BARKER, HENRY BESSEMER, THOMAS CARGILL, JABEZ CHURCH, JOHN DONALDSON, JAMES HENDERSON, JOHN WILLIAM INGLIS, HENRY JOLL, CHARLES FERDINAND DE KIERZKOWSKI, GEORGE KILGOUR, JAMES HENRY LYNDE, EDWIN MUIR, ROBERT CARSTAIRS REID, ARTHUR LEWIS STRIDE, JOHN ISAAC THORNYCROFT, and JOHN EVELYN WILLIAMS, from the class of Associate to that of Member.

Also that, under the provisions of Sect. IV. of the Bye-Laws, the following Candidates, having been duly recommended, had been admitted as Students of the Institution:—THOMAS VICTOR BAMFORD, BERNULF WATSON BEEVER, AUGUSTUS WILLIAM HARVEY BELLINGHAM, FREDERICK BENJAMIN BROWN, WALTER ASPINALL CARVER, CHARLES JOHN CORRIE, ALFRED CORRY, WILLIAM ALGERNON DARLING, HENRY BONIFACE DAVIS, SYDNEY FIRTH, AUGUSTINE SEATON GEORGE, JOSEPH GREENWOOD, SYDNEY JOHN JAMES HACK, CLEMENT HILL, JOHN EDWARD JONES, THOMAS NESHAM KIRKHAM, Jun., JOHN ALEXANDER MCDONALD, ARTHUR WOODBYNE PARISH, SEPTIMUS PENNY, ARTHUR PINE, LANCELOT GEORGE PRICKETT, FREDERICK LAWRENCE RAWSON, ARTHUR DE SAUBERGUE, WILLIAM SPINKS, HARRY LINDSAY TILLY, SAM TOMLINSON, CHARLES ROWLAND WILLIAMS, and ARTHUR PRESCOTT WOOD.

The discussion upon Mr. HOLT'S Paper, "On the Progress of Steam Shipping," was continued and concluded at this meeting.

December 11, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,523.—"Description of Cofferdams used at Dublin, Birkenhead and Hull." By WILLIAM JAMES DOHERTY, Assoc. Inst. C.E.

IN the summer of 1869 a tender from the Author was accepted by the Dublin Port and Docks Board, for the removal of the river wall at Sir John Rogerson's Quay, in the harbour of Dublin, and the erection of a new wall at a greater depth, to be carried out in accordance with the plans and specifications of Mr. Bindon B. Stoney, M.A., M. Inst. C.E., Engineer-in-Chief to the Board.

The old wall was the second which had been built at this part of the harbour, and had been constructed about the year 1820, replacing a still older wall, built at a remote period. Owing to its foundations having been laid at a depth of only from 3 to 4 feet below low water, it was practically useless for the requirements of modern shipping, as dredging could not be carried on close to it without endangering its safety. Hence the necessity for constructing a new wall, founded at a sufficient depth to allow of the river being dredged, so as to accommodate the largest class of vessels frequenting the port.

As no design had been furnished with the contract plans for the construction of the cofferdam, inside of which the work was specified to be built, it devolved upon the Contractor to design one which should meet with the approval of the Engineer, and which, by its cheapness and stability, should secure the economical and successful carrying out of the works. From the Author's experience, gained during the construction of some of the largest cofferdams in England, whilst on the engineering staff of Mr. William McCormick—as for instance that across the entrance to the deep Low-water Basin at Birkenhead Docks, and those at the Victoria Dock Extension and new West Dock at Hull, all of which had to resist great heads of water—he was enabled to form an estimate of what would be required in this present instance.

The Author is of opinion that the cofferdam about to be described (Plate 1) was one of the lightest on record, considering the work it had to do. The design consisted in having main piles, of Memel timber, 32 feet in length by 12 inches square,

driven as space piles, on the outer row 12 feet apart from centre to centre, with corresponding main piles, 40 to 42 feet long, by 12 inches square, driven as an inner row directly opposite, leaving a space of 4 feet 6 inches between, for the puddle. The space between the main piles of both the outer and inner rows was filled in with sheet piles, 12 inches wide by 6 inches thick; those on the outer row were driven 12 feet into the ground, and, reaching up to the level of high water, were 28 feet long. Those on the inner row being of a similar length, were driven down to the level of the foundation of the new wall, 24 feet below low water, their heads reaching 4 feet above low-water level.

The sheet piles on the inside of the dam were driven with their faces in a line with the main piles, so as to offer no obstruction to the settlement of the puddle; and the lower edges of the horizontal planking, 3 inches thick, with which the dam was sheeted on the inside, from the level of 3 feet above low water to 3 feet above high water, were bevelled off with the same object. Two 1½-inch tie-rods, of wrought iron, were passed through two half timber wales on the outside and the inside of the main piles of the dam. They were provided with cast-iron washers on each end, 8 inches square and 2½ inches in thickness, screwed up with hexagonal nuts. The tie-rods were placed at 1 foot below high-water level, and the other at 2 feet above low water; these tie-rods prevented the dam from spreading while the puddle was being tipped into place. The cofferdam piling, for a length of 150 feet, had to be driven during the winter, when clay could not be readily procured by dredging in the bay, the only place where clay suitable for puddling was obtainable in the vicinity of Dublin. The Author therefore resolved to substitute peat-moss, which was available within easy reach of Dublin by canal. It was expected that the peat, from its spongy nature, would not offer sufficient resistance to the pressure, and might allow the dam to collapse. To prevent this, triangular struts, 6 inches to each side, were placed in two tiers within the dam, against each of the main piles. These answered the purpose for which they were intended; but, for want of density in the peat, a hollow appeared underneath each of the struts large enough to allow water to percolate through the dam, from the joints of the piles, on the outer row, at every place where a triangular strut had been put in. The collected leakage from this cause, when the dam was closed, rendered necessary the employment of two 12-inch steam pumps to displace the water. The struts had therefore to be removed; when the peat answered admirably, becoming improved by pressure and

consolidation; although the removal of the struts caused the dam to draw together to the extent of from 6 to 8 inches.

On the removal of the old wall the masonry of which it was built was found to have been set in non-hydraulic lime mortar, so that the granite ashlar face and rubble backing were to a great extent bondless, the mortar being quite soft and pulpy.

After the exclusion of the tidal water, and when the dam had been sufficiently strutted against the old wall, a row of piles 25 feet long by 12 inches square was driven on the land side about 32 feet from the inner row of piling of the dam, and spaced to correspond with the main piles of the cofferdam. A row of sheet piling was driven, extending from the surface of the roadway to below the level of the foundation of the old wall. In this land row of piling there was a recess 10 feet deep and from 15 to 20 feet in length, in which the pumps were afterwards erected to keep the works clear of water. During the sinking of this well two sets of 12-inch plunge pumps were used, fitted with telescopic arrangements.

As the work of removal of the old wall was proceeded with, the stone of which it was built was carefully lifted, the ashlar, where suitable, was re-dressed, to be worked up again in the new wall, and the backing, cleaned of old mortar, was also used again as rubble. A steam gantry which spanned the foundations raised the old masonry. The staging for carrying this gantry was formed of uprights 9 feet high, 12 inches square, resting on the heads of the main piles of the outer row of the dam, on which were placed longitudinal runners 12 inches square, with similar uprights and runners on the land side, at a span of 50 feet, and braced with timbers 12 inches wide by 6 inches deep.

When the masonry of the old wall, and the struts against it from the dam, had been removed, whole-baulk struts, 30 feet long, were inserted, resting against the land row of whole piles and the cofferdam. A row of continuous close sheet piling, 24 to 26 feet long, 12 inches wide by 6 inches thick, was driven along the land side to support the adjacent and parallel public roadway, and to maintain it for traffic. It answered also to receive the strutting of the dam.

The general excavations were then proceeded with. As it was not desirable to have too great a weight overhead, a platform of 3-inch planks, extending halfway across the foundation, was placed on the upper tier of struts. On this platform barrow roads were worked, on the swing road principle, except that instead of working them singly, four or six barrows were wound up at

the same moment by a chain extending the length of the platform, from which attachments were made to each swing road, the whole being worked by a steam engine. In lowering the laden barrows to the stage, it was found that all dropping together, heavily laden, made the struts vibrate, and frequently broke the feet of the barrows. The Author therefore adopted small wooden cranes, instead of swing-road poles, leading the chain through a pulley at the foot, top, and arm of each crane, the whole being attached as before to the engine, worked with frictional gearing. The man in charge of the barrow on the platform swung round the crane, when the barrow had been hoisted high enough to clear the stage, and the whole set of barrows were instantly "braked" by the engine-man, and afterwards lowered gently to the stage. This application of the cranes answered well, and was a great safeguard to the men underneath. A set of empty barrows took down the empty chain, and the spaces for the wales and struts were carefully taken out.

The strata through which the piles were driven consisted of 2 feet of soft mud, 4 feet of fine sand, 3 feet of vegetable deposit overlying a thick bed of alluvial clay, ranging in thickness from 4 to 11 feet, and a bed of strong gravel, interspersed with fine sand and boulders, and in some places brown clay.

On taking out the excavations for the first length of wall, the bed of alluvial clay gave sufficient puddle for the next length of cofferdam, and so on to the end of the work. The use of peat moss was therefore discontinued. The horizontal struts for supporting the cofferdam and the roadway were placed 6 feet apart vertically for the three upper tiers, but, as the pressure increased, the distance was reduced to 5 feet. The pressure appeared to have reached its greatest intensity at 16 feet below low water, and it was found that the 12-feet distances horizontally for the struts and main piles was more than the timber could bear with safety. As in many instances the whole-timber wales were broken, particularly those on the river side, the distances were altered to 10 feet from centre to centre for the main piles and struts. To prevent the wales being nipped, or crushed at the point of contact with the struts, which were frequently indented to the extent of $1\frac{1}{2}$ inch, a facing piece, 12 inches deep by 6 inches thick, and 2 feet 6 inches long, was spiked against the wales on the front and back, and against this facing piece the ends of the struts were butted. Even with the distances reduced to 10 feet, these facing pieces were invariably splintered with the pressure; yet they preserved the wales from injury, so that a small portion could be used again

in the forward lengths. Where the earth on the land side was wet, additional wales and struts were inserted, to carry the excess weight of the spongy ground.

After the excavations had been removed, the piling for a distance exceeding 5,000 lineal feet was completely exposed to view. From careful observation the Author concludes that the direction of the piles cannot be controlled so soon as they have left the wales that keep them in place. Although in this instance the greatest care had been taken, and the piles presented a fair and uniform surface for 4 or 5 feet after entering the ground, yet, when stripped, they were seen to be very irregular. In most cases the joints were close, except where a large piece of gravel or small boulder got wedged in; but the points turned outward or inward, as the ground offered resistance, and were mostly separated from each other by intervals of from 4 to 6 inches.

In consequence of the bed of fine sand inside the dam lying immediately underneath the puddle, great care had to be taken to prevent water from getting through it. The only "blows" that occurred, directly through the dam, were caused by water making its way, little by little, first at some of the open joints or where there was a broken pile, carrying in its course the fine sand, and leaving a space underneath the puddle, which would then sink down and cause a settlement. In order to guard as much as possible against this, when the wales and struts were in place, filling-in pieces, or packings, generally 6 inches in thickness, were put in between the wales and sheet piles, and were wedged up as securely as possible, thus enabling the walings to receive the pressure directly and to rest firmly against the piling. This was always done before the excavations were carried farther than the level of the underside of the wales and struts. The least movement of the dam, if not instantly checked, caused extra trouble and annoyance afterwards, and was attended with great risk.

The foundations were taken out from 6 to 8 feet wider than the masonry of the new wall at the base; generally 2 feet in front, next the dam, and from 4 to 6 feet at the back. A wooden shoot, 18 inches wide by 12 inches deep on the inside, built of 3-inch planks, securely bolted together, and fitted with faucet and spigot joints, commencing next the pump well, was carried along the foot of the back piling, on the land side, through which the water was led into the well.

When a length of foundation, generally of from 80 to 120 feet, had been excavated, levelled, and examined, the stone was lowered into place by overhead travellers. It consisted of large

blocks of rubble, from 15 to 30 cwt. each, with a course of dressed footings, carefully built in the front line of the wall. After a layer of stone sufficient to cover the area of the excavated foundation had been laid, cement concrete was tipped in from a stage, and the spaces between the larger blocks of rubble were filled in with the concrete so tipped, and smaller pieces of stone rammed, packed, and tucked with "swords and knives" made specially for this purpose, so that no crevice was left unfilled. A layer of concrete was placed between the stones, to prevent them touching each other. When the footing courses had been sufficiently built up through the first tier of struts, short struts were placed against the wales of the cofferdam, and rested against a distributing piece on the face of the footing course. After allowing from eighteen to twenty-four hours for the masonry to set, and after filling the space behind the wall over the drainage shoot with carefully selected material, the bottom tier of struts was removed, to admit of the masonry being built up for the next 5 feet through the second tier of struts; other short struts, and the back filling, being repeated as before, and so on through every tier of struts till the full section of the wall had been built. The struts in all cases, up to the level of low water, had to be cut out, the great pressure not permitting their removal by other means. The open end of the wall was brought up in steps, with a series of breaks of 8 feet each, to insure the proper bonding of the succeeding lengths.

The whole of the masonry was built with Portland cement. The rubble backing was built with concrete, composed of 1 part of cement to 6 parts of coarse gravel and sand. The mortar for setting the limestone facing and granite ashlar facework was composed of 1 part of cement to 4 parts of screened sand. All the gravel and sand were obtained by dredging, and were prepared and mixed in one of Mr. Stoney's concrete mixers.[1]

The wall, up to 1 foot 6 inches above low water, was faced with close punched limestone, obtained in the vicinity of Dublin, 2 feet in the average thickness of the bed, laid as broken ashlar. From that level to the coping the facework was fine-dressed granite, from the Dalkey quarries, laid in horizontal courses 12 inches in height, with every third stone a header, averaging 3 feet on the bed, the stretchers averaging 1 foot 6 inches on the bed. The width of the wall at the base was 19 feet 6 inches, with a dip

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 348.

landwards of 6 inches; the extreme height was 42 feet 7 inches from the base to the coping, except where soft springs or pulpy clay had been excavated, where it was cleared out for the full width of the foundations. For a distance of from 250 to 300 feet the average height of the wall was 46 feet 7 inches, being carried down to 28 feet 6 inches below low water. The granite coping extended across the full width of the wall, 5 feet at the top, and was 2 feet 1 inch in thickness. Face moorings of 3-inch round iron, with rings 15 inches in internal diameter, were placed at every 150 feet apart, at the level of high water, and were recessed their own thickness into the face of the wall. Surface moorings with two hooks on each, resting on the coping, and extending a distance of 9 feet behind the wall, anchored with a granite block, and tested to a strain of 36 tons, were placed at 60 feet apart. One set of stairs, 4 feet 6 inches in width, with a landing at 1 foot 6 inches above low water, occurred at every 400 feet.

The wall throughout its entire length has not shown the slightest symptom of settlement, and will bear comparison with any other structure of the kind in the United Kingdom.

The river opposite has been dredged to a depth of 22 feet at low water; thereby giving floating accommodation at all times of the tide to the largest sea-going ships. Since the construction of this wall the grain trade of the port, by which this part of the harbour is principally taken up, has been more than doubled.

The wells to receive the drainage were sunk to an average depth of 30 feet below low water, and were formed on the embayed sides with close sheet piles similar to the back piling. A row of short sheet piles was driven on the open side from the level of the base of the wall. A platform of 3-inch planking was placed across the bottom of the well, upon which two sets of chain pumps were erected, each 18 inches by 8 inches, which raised the water to a level of 2 feet above high water and discharged it into a shoot at the top, from which it passed over the cofferdam into the river. One well was sufficient to drain a distance on each side of from 350 to 400 feet. To keep the shoot leading to the well from being choked with fine sand, the open end, next the workings, was temporarily stopped, and an upright shoot inserted therein, and, as the excavation proceeded, pierced at different levels with holes, to receive the water, allowing the fine sand to settle in a small sump close by.

In taking up the masonry of the old wall an opportunity was presented of examining the strength of cement concrete. Behind the old wall the foundations for a 30-ton crane had been

laid, ten years previously, by Mr. Stoney, consisting of a pivot well, lined with brickwork, 3 feet thick, set in cement mortar. The pivot step and the bed plate of the crane being fastened down through the same, rested on a foundation of concrete, composed, so far as the Author could judge, of about 4 parts of gravel to 1 part of cement. The bond of the brickwork was so perfect that steel wedges used in its removal generally broke the bricks. The concrete foundation, of which the contents were 2,400 cubic feet, had become one solid block. Holes 16 to 18 inches deep were drilled, and charged with about 3 inches of powder to each hole; four or more holes were fired simultaneously, by which means the concrete was torn up into large irregular blocks of from 3 to 5 tons each, with a few smaller pieces. The materials of which the concrete was composed were similar to those used in the construction of the new wall, being clean sea gravel, full of small boulders or paving stones from 1 lb. up to 5 lbs. in weight, with an admixture of gravel and sand. When broken up it was moist, but dried when exposed to the air.

So soon as a length of about 200 lineal feet of wall had been built, a cross dam was constructed between the wall and cofferdam by fitting a timber 12 inches square against the face of the wall, opposite a main pile of the cofferdam, and bolting thereto vertically, at intervals of 5 feet, horizontal framing 12 inches wide by 6 inches deep; within which 3-inch close sheet piling was driven. Raking struts were carried from the whole timber against the wall, and secured to the main piles of the dam at suitable distances. Clay puddle was tipped in behind the sheeting; and a row of short piles was driven in at the toe of the slope of the puddle, to prevent it spreading. This enabled the cofferdam to be drawn for the length thus cut off. The drawing was accomplished by a frame termed a "gallows." This, which was about 9 feet high, consisted of two uprights 12 inches square let into a frame, 12 inches wide by 6 inches thick, and stayed back thereto. Upon the uprights rested a cross piece of elm 12 inches square. From this cross piece two three-sheave blocks were suspended, through which a short link chain, $\frac{3}{4}$ inch in diameter, was reeved, with the running end passing through a snatch block, secured to a cross piece of hard wood, made fast to the foot of the gallows. The chain led to the drum of a strong double-purchase crab winch, fastened to two longitudinal runners, 12 inches square, placed as a road on the top of the dam. The gallows was moved on the runners on small iron rollers over the pile about to be drawn, and the sling chain attached to it.

On drawing the piles of the first section of the cofferdam, it was

found that where the piles and struts had been 12 feet apart, nearly the whole of the inner row of the dam had broken off at about 6 feet from the bottom, or at 18 feet below low-water level; and that where the 10-feet spacing had been adopted very few of the piles were broken. As a rule, although the piles were not shod, very few of the points were injured by the driving.

At the "return" to Great Britain Quay, the cofferdam was extended in a direct line with Sir John Rogerson's Quay, 100 feet into the river; returning to the Grand Canal Dock entrances, the depth of water for more than 250 lineal feet was 14 feet at low water, so that it was considered advisable to drive a double dam for a distance of 100 lineal feet in the deepest portion of the water, with dams at right angles, and at short intervals, to the old wall of Great Britain Quay, to lessen the risk attendant upon the exclusion of so much deep water.

To prevent the dam from being pressed outwards, a foreshore of dredged material was deposited on the outside up to the level of low water, and piles and struts were placed from the inner dam landwards. Besides being in a great depth of water, it was discovered that the bed of gravel upon which the wall was founded dipped considerably at this place; consequently the piling had to be driven to 28 feet below low water, the depth at which the sound gravel bed was met with.

The greatest amount of leakage always took place at the junction of the forward cross dam against the old wall, through which the only serious "blows" occurred. The footings of the old wall extended underneath the cross dam, thereby preventing the sheet piles immediately abutting against the wall from being driven farther than the footings; and as the bottom rows of old ashlar had been built with but little mortar, the water permeated through the courses for a distance of from 50 to 100 lineal feet beyond the junction of the wall and cross dam, washing away the fine sand foundation on which the wall rested.

After one or two "blows" from this cause, the Author drove a row of close sheeting 12 inches wide by 6 inches thick across the excavations, in two tiers, at the distance intended to be taken out as a length, the top tier sufficiently high to prevent the sand from being washed over. From this up to the old wall, a layer of puddle, well weighted, was placed. The "blows" were thus prevented. The excavated material was also tipped for a foreshore on the outside of the dam, which greatly assisted in equalising the pressure from the land side, and so prevented the dam from "working" with the rise and fall of the tide.

The total length of river wall was 2,310 lineal feet, built at the contract sum of £131,728, or at the rate of £57 10*s.* per lineal foot, exclusive of dredging the foreshore from low-water level to the present level of the bed of the river opposite this wall, namely, 22 feet below low water.

The entire quantity of masonry was 44,500 cubic yards, consuming 85,500 tons of stone and gravel.

The timber in the cofferdam strutting, staging, &c., amounted to 156,000 cubic feet of whole and half timbers, and 21,000 cubic feet of planking. Timber not cut up and wasted on the work, when removed, was of little service, except for rough staging on works of a similar class, owing to the quantity of bolt-holes and spikes with which it had become studded.

Constant supervision had to be observed in carrying out the works, most of the materials having been conveyed overhead during the time men were working underneath. Fortunately no serious casualty occurred in connection with the works.

Considering that cofferdams occupy a place of the first importance in most temporary arrangements for the exclusion of water from the sites of docks and harbour works, the Author is of opinion that a few additional examples of what has been done, with a statement of the difficulties encountered, will be acceptable. He therefore proposes to describe two of the cofferdams previously referred to, viz., the cofferdam at the Low-water Basin, Birkenhead, and the cofferdam at the Victoria Dock Extension, Hull.

The Cofferdam across the Entrance to the Low-water Basin, Birkenhead (Plate 2).

Mr. John Ellacott, M. Inst. C.E., in his Paper on the Low-water Basin, Birkenhead,[1] alludes to the destruction of this cofferdam, and the Author, who was engaged on the works for the contractor and made notes at the time, is enabled to describe its construction and to place the most prominent particulars of the work before the Institution.

This cofferdam was constructed in the years 1859–1860, and was on plan the segment of a circle whose chord was 467 feet, and versed sine 76 feet. The width at the top of the dam was 18 feet, and at the ground line 23 feet. Its extreme height from the toe of the outer row of piles to the top of the dam was 61 feet

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 525.

6 inches. The dam was formed with two rows of whole piles, battering both ways, the outer row in lengths of 35 to 40 feet, 12 inches wide by 14 inches thick, driven close as sheet piles, with toes reaching to 35 feet below Old Dock Sill; the inner row, 30 to 35 feet long, of the same width and thickness, driven also as sheet piles, with toes reaching to 30 feet below the same datum. On every fourth pile of both the outer and the inner rows was placed an upright 12 inches wide by 14 inches thick, by means of a scarf 4 feet long, secured by four 1-inch bolts, reaching to the level of 3 feet above H.W.E.S.T., the whole being secured by five tiers of wales, placed on the outside of the piles and uprights at vertical distances of about 8 feet. Through these wales were passed, at longitudinal distances of 12 feet, a series of 2-inch wrought-iron tie-rods, screwed up on each end with hexagonal nuts on cast-iron washers 9 inches square by 2 inches thick.

At the level of high water of spring tides, an inner wale, 12 inches square, was fixed on both outer and inner rows of uprights, to which diagonal horizontal struts or braces, 12 inches square, were bolted, for the purpose of keeping the uprights asunder to the proper width at the top. The whole of the interior of the dam on both the outer and the inner row of uprights, from the level of Old Dock Sill to the top, was sheeted with horizontal planking, 3 inches in thickness, to hold the puddle.

The original surface of the foreshore at the centre line of the dam was about 10 feet below Old Dock Sill, rising gradually at either end of the segment to about 7 feet below Old Dock Sill. The excavation within the dam was taken down to 18 feet below Old Dock Sill before the puddle was put in. The ground upon which the dam rested was chiefly fine sand; this, when saturated with water, became a quicksand.

The timber specified to be used was crown Memel, but it was ascertained, when piling proceeded, that for half the distance on the north side, and about 90 feet on the south, the Memel could not be driven on account of the compactness of the sand, and American elm piles were substituted.

Excavating within the dam was a difficult operation, requiring to be done as tide work in short lengths. Two sets of chain pumps capable of throwing 2,000 gallons of water per minute were fully employed in carrying the excavations down to the specified depth.

After the dam had been filled with puddle to the height of 12 feet above Old Dock Sill, the cast-iron washers began to sink into the wales and to break. To remedy this, pieces of American elm

3 feet long by 12 inches wide by 6 inches deep were placed under the washers. Then the wales exhibited signs of giving way where the tie-rods passed through. As a precaution, additional wales were put on between each of those originally in place, with an extra tie-rod driven through each additional wale at the intermediate distances, with a vertical piece of elm overlapping two wales, so as to distribute the bearing surface. The tie-rods were screwed up over these vertical chocks. This proved effectual in keeping the puddle in place.

When the puddling of the dam was near completion, the structure showed symptoms of going out towards the river, particularly near the crown of the segment. To prevent this, an extra row of piles was driven for a distance of 200 lineal feet, at 30 feet outside the dam, 8 feet apart from centre to centre, upon which a waling 14 inches square was bolted as low down as the lowest tide would permit. From this waling, raking struts 14 inches square were placed, reaching to the underside of the wale on the dam at the level of 8 feet above Old Dock Sill. It was considered expedient, during the time the dam was in place, not to remove a quantity of contiguous soil intended to be excavated, so as to prevent a "blow."

All the other portions of the work within the Low-water Basin being completed, Mr. Lyster, M. Inst. C.E., the Engineer to the Mersey Docks Board, ordered the excavation to be proceeded with; the object, as stated by Mr. Ellacott in his Paper already referred to, was "to lessen as much as possible the subsequent dredging." Wagon roads were therefore put in by the Contractor, and the work rapidly proceeded.

When about five-sixths of the excavations had been made, the water commenced bubbling up in half-a-dozen places, at about 30 feet behind the dam. Observing this, the Engineer ordered additional struts to be placed on the Basin side, as the structure commenced to warp a little, and the puddle to settle down slightly; the bubbling up of the water, however, continued, and after a day or two the nuts of the tie-rods began to fly off. It seemed evident that the dam would not much longer resist the undermining and the pressure from without. The Contractor, therefore, removed his wagons and some of the rails; but a large portion of the latter remained behind, when, on the morning of the 18th of June, 1863, the dam suddenly gave way.

The head of water, 33 feet deep, rushing in to fill the empty space of 14 acres, scoured a channel 30 feet in depth and 50 feet in width within the Basin. A large portion of the piles were broken

off short, rendering the pulling of the stumps exceedingly difficult. The removal of the wreck left standing was speedily proceeded with. Swing roads lifted out the clay puddle, and the piles were drawn by floating derricks at the rate of about four per tide. Where the American elm piles had been driven, it required a salvage lighter of about 70 tons lifting power to draw a single pile. To facilitate the work, compressed-air pontoons were hired from the Salvage Company of Manchester; the lifting power of these pontoons was beyond what was necessary, but their tubular shape rendered it difficult to attach them to piles, and eventually, when the bulk of the cofferdam had been drawn, arrangements were made with the Engineer to draw all the stumps by a floating derrick, divers attaching the chains as the work of dredging proceeded.

The total cost of the cofferdam was £28,000, or £56 per lineal foot. The 80,000 cubic feet of timber used in its construction, when drawn out and stacked on shore, sold for £1,100.

Cofferdam across the Victoria Dock, Hull (Plate 2).

This dam presents another variety of shape and size, and was subject to a constant instead of to a tidal head of water. It was one of a series constructed by Mr. William McCormick, designed for the extensive docks at Kingston-upon-Hull by Sir John Hawkshaw, to allow the trade of Victoria Dock to be carried on without interruption during the time an extension of 7 acres was added to the water space of that dock. It was almost straight, 470 feet long, and consisted of two rows of whole piles, each 40 feet long by 13 inches square, driven as close sheeting about 10 feet into the ground and 6 feet apart between the inner surfaces. It was braced together with two sets of wales 13 inches square, one set at the level of high water in the dock, and the other at 6 feet below high-water level. Through each of these a 2-inch tie-rod passed, and was screwed up on timber chocks and washers on the outside of the wales. The deposit of mud, 7 feet in depth within the dam, was cleared out with bag and spoor dredger, before filling it with puddle.

The water remained at nearly the same level on both sides of the dam during the excavation of the soil in the extension of the dock. When the works had been so far completed, that nothing remained but an embankment 40 feet wide at the base underneath the pitching, and the concrete bed of the slope, parallel with the dam, the water on the extension side was lowered by a siphon

into the 7-acre area. After the water had been thus lowered 6 feet, the dam showed signs of yielding. Shoring struts 14 inches square were therefore placed against the walings and pitching of the slope, and the water was further run off.

The pressure then showed itself greatest near the level of the accumulated mud, and it was found necessary to drive stay-piles in the slope 8 feet apart, from which struts were placed, resting against an extra wale 13 inches square, fastened to the dam at the level of the mud; it was also thought prudent to fill the 7-acre extension with 13 feet depth of water. There were good grounds for this precautionary measure, as a spring of water, evidently from the docks, suddenly appeared when the slope pitching on the north side was approaching close to the dam.

The mud behind the dam was cleared out in short lengths, and the pitching cut out, commencing at the bottom. This pitching was 15 inches in depth, resting on a bed of concrete 12 inches thick, and had been laid in blue lias lime. Its bond was so strong, that a sheet 30 feet long by 8 feet wide would come off in one piece, which had afterwards to be cut with wedges. The pitching was first taken up next the bottom to allow the shores and stay piles to remain intact as long as possible. The pressure from the dam was so intense that many of the stay piles were pressed 1 foot into the solid bank. So soon as the great bulk of the pitching had been removed, the water was permitted to rise in the extension to the same height as in the dock, thereby averting further risk to the shipping lying therein.

The dam was drawn by an old steamboat hulk of 250 tons burthen, on the deck of which was placed a 10-HP. portable engine and winding drum. Over the stern was fixed a frame with pulleys and chain attached to the pile; the hulk was then sheared down, and in a short time the pile would come up with a bound. In this way twenty to twenty-five piles were pulled out daily. The cost of the cofferdam was about £21 per lineal foot.

This communication is illustrated by drawings, from which Plates 1 and 2 have been engraved.

[Mr. GILES

Mr. A. GILES remarked that, as far as he could judge from the diagrams and plans of the two dams at Birkenhead and Hull, it might have been foreseen that they were not strong enough for the work that they had to perform. With regard to the dam at Dublin, it had been stated in the Paper that the shores were put 12 feet apart horizontally, with a pressure of 20 feet of water upon the dam. Any one who had constructed dams would know that that distance was excessive. He had himself constructed many dams, and at so high a pressure he had never dared to put struts at a greater distance than 6, 7, or 8 feet; and under a pressure of 25 or 30 feet head of water the struts used by him were generally about 6 feet apart. The bolts were, in the Dublin dam, about 10 or 12 feet apart. He thought that was an error. Bolts, particularly in the case of a dam of so great a height, should never be more than 7 or 8 feet apart. The most startling thing, however, was, that in a dam of such depth there were only two walings, those being 15 or 16 feet apart. It was contrary to his experience that such a dam could stand with so small an amount of waling and bolt, and he wished to ask whether the Author considered the dam sufficient for its work, or whether there was any failure or leakage owing to the intense strain on the bolts, and to the distance between the struts.

Mr. JOHN DIXON observed that, after looking at various cofferdams, the question often arose in his own mind, whether there was any necessity for a dam at all, and he thought that in many cases cofferdams might be dispensed with, especially considering the mechanical appliances which year by year were being supplied, and also considering the advantages presented by the use of the new building material, concrete, which he regarded as merely in its infancy. What was done in constructing a bridge, pier, or quay wall? Practically two walls were built: first a dam was constructed, probably at as much expense as the finished wall; the water was drawn from the inside, and a trench was made, into which concrete was put. Generally the concrete was put in wet; and it occurred to him as a question for the future consideration of engineers, whether the concrete might not be put into the trench direct. The concrete wall might be carried up to the height of low water, and completed with stone facing, or other material.

Mr. HAYTER said that the Author had described the dam erected for the construction of the works of the Victoria Dock Extension at Hull as being almost straight. He had been associated with this work and would state that the great feature in that dam was that it was not straight, but the segment of a circle. He admitted

that the radius was flat, 1,500 feet, and the versed sine was 20 feet. It had occasioned a great deal of anxiety during the time the dock works were in progress, as there were always ships behind it in the dock, and if the dam had failed the result would have been disastrous. Fortunately it had stood, and the reason he assigned for it—apart from the care bestowed upon its construction by the contractor, Mr. McCormick, and by his engineers—was that it had been made of a circular form, according to Sir John Hawkshaw's design, and that it acted as an arch. Soon after the construction of this cofferdam Sir John Hawkshaw had to make another dam for the construction of the eastern entrance of the South Dock of the West India Docks, which was also circular, but the curve was much sharper, the radius being 150 feet, the versed sine 50 feet. There was nothing particularly novel in the design of this dam, except that, the curve being so sharp, resort was had to a new mode of making the walings, which, instead of being of timbers of large scantling, were of laminated planks, care being taken effectually to break the joints of the planks. Sir John Hawkshaw had also constructed a cofferdam in the Zuider Zee, near Amsterdam, which was a complete circle, the radius being 525 feet. It was made to construct works on the Amsterdam canal, and it was on silt and soft material throughout. It was a difficult and very interesting work, but as he hoped soon to present a Paper to the Institution on the Amsterdam Canal and the North Sea Piers, he reserved the description of that dam. The thickness of the puddle in the Victoria Dock dam at Hull was 6 feet, and in that of the West India Dock dam 5 feet. In both those dams the usual system of through bolts was employed to connect the two rows of piles, but he believed that such bolts were mischievous. The puddle could not be got tight round them; it sank and left vacuities about the bolts; and although the puddle was often well rammed, he believed that dams with through intermediate bolts almost invariably leaked. In some large cofferdams that he had recently been associated with, constructed for the purpose of carrying the East London railway through the London Docks, intermediate through bolts had been altogether dispensed with by Sir John Hawkshaw, and the thickness of puddle between the two rows of piles was reduced to 4 feet 6 inches. Instead of these through bolts, buttress piles were driven at intervals outside the dams to withstand the pressure of the puddle within. These dams had to penetrate a bed of gravel about 12 feet deep, and piles could not be driven through it. In order, therefore, to construct the dams, a trench was excavated through the gravel down to the London clay; that trench was

filled in with clay, into which the piles were driven. The clay was thus consolidated, and the plan of procedure answered. He could state as the result of a very large experience in the construction of dams that, as a rule, it was desirable to dispense with intermediate through bolts, retaining only the top row; to have as little thickness of puddle as possible; and to have no horizontal irregularities or ledges to catch the puddle, so that it would settle down uniformly. Of course dogmatic laws could not be laid down applicable to every case. If, for instance, the ground were very bad, and insufficient to enable the piles to have a firm hold, it might be necessary to have resort to through bolts at the bottom, at or near the ground line, to connect the piles together. The conclusions he had mentioned being the result of considerable experience, he hoped that they might be of service to gentlemen who might be called upon to construct such works which were sometimes of a very difficult character.

Mr. BRUNLEES observed that in the Avonmouth Dock, recently completed, he had formed a dam upon a different principle from any of those described in the Paper. The foundation consisted of a single row of piles driven closely together. Above the level of the sill the dam was formed of what might be termed a lock-gate, with planking on the outside, thoroughly caulked. The dam was strutted in the usual way from the inside. The head of water was 44 feet, so that it was necessary to be very careful. At Lynn, where he had constructed a dock some years ago, he had used the double pile and puddle in the manner described in the Paper. At Whitehaven he had used a dam of earth in front of the lock. Considering that in the one case the head of water was 42 feet, and in the others only 22 feet, he believed that the timber dam, well caulked, was far superior to the others. He might add that the timber dam was much cheaper, because the whole of the timber was fit for use after its removal. In the one case there was only labour to pay for, and in the other cases there was the material also.

Mr. BRUCE thought that in driving 6-inch piles instead of whole-balks an inefficient dam was sometimes made, and more money spent in the end, because there was much more water to contend against, and greater difficulty in keeping the dam tight. Thirty years ago at Berwick Bridge, where there was a good deal of cofferdam work, 6-inch piles had been abandoned for that reason alone. By the use of whole-balks less timber was destroyed in the end, the dam was made more easily, and the foundations were got in more cheaply. That might not be so

in every case; but he believed it was so in many instances. In the cofferdam at Birkenhead the piles were said to have been battered both ways. The puddle was narrower at the top than at the bottom, so that in sinking it would leave the sides of the dam inside, and it would necessarily be very difficult to keep it tight. He had never seen a dam made in that shape, but it appeared to him that it was not a very good one, having regard to the necessity of keeping out the water. From the fact that at Dublin the piles were not shod, he gathered that the ground must have been comparatively soft. The Author had not stated what kind of timber was used, but he presumed that it was Memel. For that class of work he thought that the American rock elm, at all events where the ground was hard, was a much better timber than Memel. Less of it was destroyed, and it was more valuable when sold again. The walings were entirely on the outside. Of course it was the right thing to have none inside, so as to allow the puddle to settle; but he imagined that if the piles got out of line it was a good thing to have, while driving, a temporary waling inside.

Mr. Woods thought that the mode of constructing quay walls referred to by Mr. Dixon was applicable under certain circumstances. He was himself constructing a quay wall at Bilbao on that principle. He simply drove sheet piles in two lines, the interval between corresponding with the width of the wall. The foundation was compact sand, which he was enabled to remove by the Woodford sand pump; and the trench was filled in with concrete. He could excavate to a depth of 12 or 15 feet. The work was not completed; but, as far as he could judge, he believed the plan would prove successful.

Mr. Prince wished to call attention to the strange neglect, on the part of eminent engineers, of the system of under-sinking foundations. As a rule Indian engineers avoided cofferdams, and adopted the old native system of under-sinking; and he recommended members of the Institution who were about to undertake works of that kind to look into that system, which would save an enormous amount of unnecessary expenditure.

Mr. Russel Aitken agreed with Mr. Dixon in thinking that the system of cofferdams was very expensive, and might often be dispensed with. He had himself dispensed with it in the construction of the Mazagon pier in the harbour of Bombay. He drove sheet piles, and filled in the space between, 16 feet wide, with liquid concrete; and the work had been entirely successful. He had seen the cofferdam at Hull, referred to by Mr. Hayter, when the works were nearly completed. It had assumed a most

irregular form, so much so that he had recommended the engineer in charge not to repeat it. A cofferdam with a radius of 1,500 feet received no support from the fact of its being circular. For every ton per lineal foot the pressure was 1,500 tons; so that with such a flat radius there could be no efficient strengthening power.

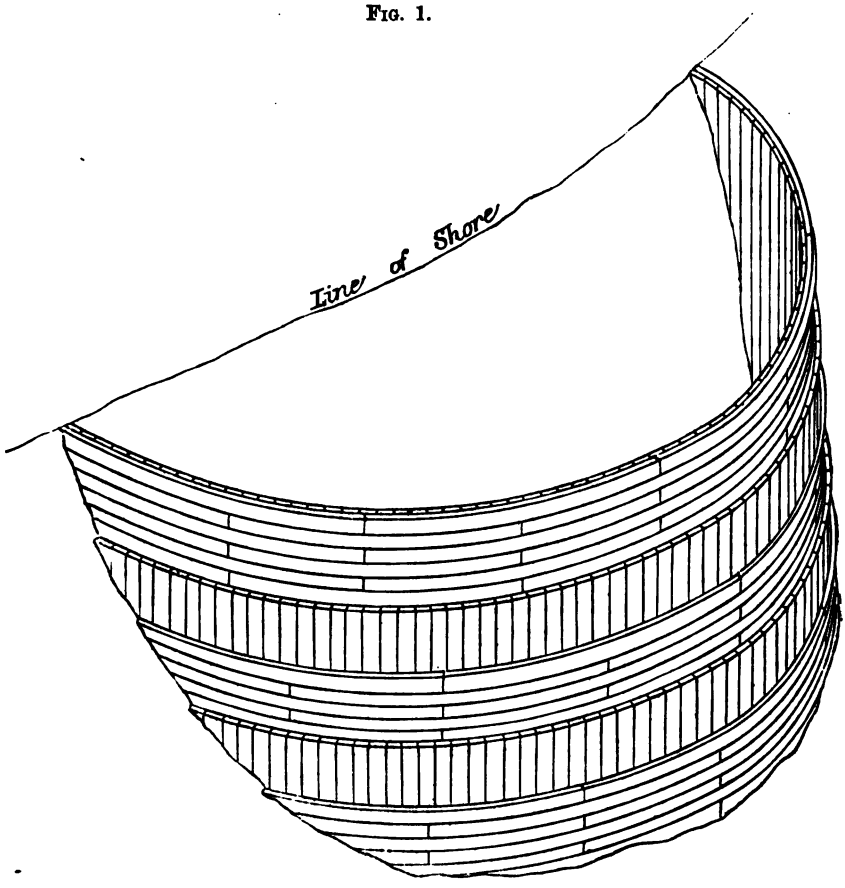
Mr. DOHERTY, in reply, said he had great pleasure in informing Mr. Giles, who objected to the 10-feet spaces in the dam at Dublin, that the work had stood remarkably well. Mr. Dixon had raised the question whether any dam was necessary. Such dams, however, had been used in the construction of the Thames Embankment, and if they were good for London, he saw no reason why they should not be made in Dublin. With regard to the dam at Hull, Mr. Aitken had pointed out the very slight advantages to be obtained by a curved dam of 1,500-feet radius, the dam itself being only 470 feet long. He was glad Mr. Hayter had adopted a puddle wall 4 feet 6 inches instead of 6 feet thick. Mr. Doherty had been led to adopt 4-feet 6-inch puddle, notwithstanding the example of Hull. He believed few of the younger members of the Institution had had more experience in cofferdams than himself. He had had experience of the great dam at Birkenhead, and of all the dams erected by Sir John Hawkshaw at Hull; and he had erected a length of 2,500 feet, as described in the Paper; he was also erecting other dams at Dublin, in connection with the rebuilding of the Carlisle Bridge and another new bridge over the Liffey; and the conclusion at which he had arrived was, that if the puddle were held closely together, a wall 1 foot thick was as good as one of 10 feet for excluding water. With regard to the remarks of Mr. Brunlees about a single row of piles, he was at the present time constructing a dam in accordance with that system. He thought he had made an improvement in the ordinary mode of driving a single row of piles for the formation of a dam. He had joined three piles into one by sawing the edges straight, and fastening the three piles together by means of 3-inch elm dowels let into the joints, 3 inches into each pile, and at distances of about 8 feet apart, then fastening the piles together with 1¼-inch wrought-iron dogs, the interior joints being caulked previous to being driven, so that after they were driven he had only every third joint to caulk. He agreed with Mr. Brunlees that where there was not a great head of water, and where there was no danger of the dam being floated out, a single row of piles was proper. He took no credit for this plan, because it had been provided for in Mr. Stoney's specification. He had also another form of dam in

operation, where there was a great head of water, and the thickness of the puddle was 4 feet 3 inches. The dam was driven with half-timber sheeting. It was 200 feet long, and it inclosed a pier and an abutment of a new swing bridge. The foundations of the pier, extending down to the gravel bed, were 18 feet below low water. In that case there was no foreshore, but simply a head of 19 feet 6 inches of water to be resisted; that was done by a single dam with a wall of 4 feet 3 inches of puddle, with sheet piles, struts, and wales, the struts being 10 feet apart from centre to centre. He agreed with Mr. Bruce with regard to the superiority of American elm over Memel for hard driving. In 1851 Mr. Bruce described a cofferdam across the Tweed, where he had first used Memel, and then, finding it to be too soft, adopted American elm; but even then the dam was not a very great success, because it could only be used at low water. He quite agreed that in many instances a dam could be avoided altogether, but that was not the case in the work which he had described. It was only by driving a dam that the roadway over which all the traffic passed could be kept up. Water had to be excluded on one side, and the roadway kept up on the other, and between the two a river wall had been sunk to a greater depth, he believed, than any on record—28 feet below low water—and in immediate contact with the tidal river. Temporary waling inside, referred to by Mr. Bruce, had been adopted by him. Mr. Woods' plan of driving two rows of sheeting, taking away the old wall, and filling up the space between with concrete, would not have answered.

Mr. STEPHENSON, President, said that he had discovered, many years ago, in building retaining walls and large sluices in the fens, that a thick wall of puddle was a mistake. It was the custom in those days to use puddle 4 or 5 feet thick behind walls; and the result was that when it sank down it generally did so in a body; but if put in 14 or 18 inches thick, the pressure made it follow down the wall instead of settling away from it. In Holland the sea banks were made with silt that melted like sugar in water. He had been engineer-in-chief for the construction of some of the heavy banks in that country. The slopes on the sea side were 5 or 6 to 1, and on the land side 3 to 1, giving several hundred feet for the base; and the only safeguard against the water coming on to the land was a thin wall of inferior clay in the middle of the bank. The whole of Zealand, he believed, was at the present time embanked in that way: showing the efficacy even of the bad clay there used if it were only well compressed. He believed the Author was right in his conclusions on the subject of puddle.

Mr. H. Law, through the Secretary, described a cofferdam, or shield of timber, which had been designed by him and employed in constructing the entrance of a graving dock at Rio de Janeiro. The shore being bare granite rock, an ordinary cofferdam of piles would have been impossible. The site of the proposed entrance was enclosed by a shield of timber, the bottom of the shield being cut to the shape of the rock against which it was to be placed. This shape was measured by constructing a temporary stage of the same form as the intended shield; the vertical depth was then taken with a rod at distances of 6 inches apart; and thus a series of ordinates were obtained, to correspond with which the bottom of the shield was cut. The shield (Fig. 1) was built upon the same

Fig. 1.



temporary stage in a horizontal position, the first or inside layer of planks being placed close together upon templates formed to

the requisite curve, just in the same manner as the lagging of an ordinary centering. In the next layer the planks were bent round the circumference at right angles to the former, being secured at each intersection by a 5-inch spike; then succeeded another layer of planks parallel to the first, and similarly secured; then another parallel to the second, and so on, until a total thickness was attained of 18 inches, consisting of six planks of the ordinary dimensions, 3 inches thick by 9 inches wide, by 14 feet in length. The number of thicknesses of plank was increased according to the depth of water, the upper 5 feet consisting of only two thicknesses, and an additional plank being added at each additional 5 feet of depth. The shield was constructed in three weeks by half a dozen ordinary carpenters, and was caulked in two days; when completed it was lowered without difficulty into place, being loaded with sufficient ballast to counteract buoyancy. It simply bore against the rock at either side, there being no struts or bracing of any sort; a few pine wedges were inserted on the inner side wherever the shield was not in actual contact with the rock. Mr. R. G. Cunningham, who superintended the erection, wrote, "It proved a most brilliant success; I must confess that I never anticipated it would have been so strong and tight; we built in the sill of the dock and completed all the channel with perfect facility as if we were working on dry land. When we removed the ballast from the shield it floated, I towed it away, and the dock was ready to receive the steamer the 'Incansavel.' I may add that I recovered nearly all the timber used in its construction, and employed it in flooring coal lighters and the two large pontoons I have here."

Mr. STONEY observed, through the Secretary, that his specification of the Dublin cofferdam provided that the dam should be made with double sheet piling and puddling clay between, so as to be watertight, and high enough to exclude tides rising 3 feet above standard high water; and that both sides of the foundation pit should be closely sheet-piled to a depth of 25 feet below low water, so as to prevent the water from the bottom of the river coming in or the road sinking, with whole-balk wales and whole-balk struts across the pit, and that the excavated material should be thrown outside the dam, so as to form a foreshore to stiffen and support the dam. The minimum width of the foundation pit also was specified. It would be observed that the cofferdam[1] had the

[1] The term "cofferdam" here includes the puddled dam, front and back piling of foundation pit, wales, cross struts, and other timber work forming the coffer or enclosure within which the quay wall was built. Sometimes the term is restricted to the dam alone.—B.B.S.

river on one side and a public quay bounded with houses on the other; it was essential that the quay and houses should be kept from sinking or moving in any way, and as the pressure of the earth beneath the quay, and which was retained by the back piling of the foundation pit, was communicated by the cross struts to the dam on the river side, the simplest and most efficient way of providing the necessary resistance was to throw the excavated material out on the foreshore of the river so as to form a bank outside the dam capable of resisting the thrust of the earth communicated through the cross struts in the foundation pit. The total length of the cofferdam, measured along the exterior of the puddled dam, was 2,437 feet, and the price paid the contractor was £36,500. This included the puddled dam, the front and back piling of the foundation pit, cross dams, struts, and everything connected with the construction, maintenance and removal of the cofferdam. The cost per lineal foot of cofferdam was therefore £15, and its cost per lineal foot of quay wall was £15 16*s*. These prices contrasted favourably with those of other cofferdams, having regard to the fact that the foundation pit extended in depth from 43 to 46 feet below the surface of the quay, and from 38 to 41 feet below high water of equinoctial spring tides with 13 feet range of tide. The contractor, however, was fortunate in having retentive clay both in the bed of the river and inside the cofferdam, so that the quantity of water to be contended with was comparatively small. Mr. Stoney had constructed departmentally, on the north side of the river in Dublin, a quay wall somewhat similar to that described in the Paper. It was 784 feet long and extended to 33 feet below high water. This wall was finished in 1869, and as the cofferdam was probably the lightest on record for such work, it might be interesting to have it described in the proceedings of the Institution. In general form and arrangement it closely resembled that adopted subsequently at the south quay, as described in the Paper; but the characteristic feature consisted in the slightness of the sheet piling, which was formed of 3-inch American spruce planks, requiring therefore only one-half or one-fourth the quantity of sheeting, and that of a cheaper class of timber than if it had been half or whole-balk piling. The ground below low water level was gravel, full of boulders and porous as a sieve. Whole-balk piles refused to penetrate it more than a few feet, and when taken up their points were generally broken off or broomed up, and the only way the sheeting could be got down was by excavating a few inches below each pile, and then tapping the pile with a small ringing engine with a 4 cwt. ram worked by hand.

The quantity of water, which chiefly came through the bottom of the foundation pit, was very great, and required the use of several powerful steam pumps, which raised collectively 14,000 gallons per minute. The wall was faced and coped with granite ashlar. The total cost, including masonry, machinery, cofferdam, pumping, and every expense of construction, was £28,000, or £35 14*s.* per lineal foot of wall. If, however, the old plant remaining after the completion of the work was valued at only £2,000, the cost would be £33 3*s.* per lineal foot. The cofferdam was represented in isometric perspective in Plate 3. The actual cost unfortunately had not been kept distinct from that of the rest of the work; though unlikely to have exceeded £10 per lineal foot. At the present time the Author of the Paper was constructing under Mr. Stoney's specification abutments for a new bridge in Dublin, behind a dam formed of a single row of whole-balk sheet piles with sides sawn parallel and driven in close contact and having the joints caulked with oakum like the planking of a ship. This dam had up to the present given great satisfaction. It was water-tight, and, as it required only one row of piles and no puddle, it was likely to prove a valuable type of dam. The depth of the foundation pit was 17 feet below high water and 25 feet below the surface of the street.

ANNUAL GENERAL MEETING.

December 18, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

THE notice convening the meeting having been read,

Messrs. J. D. Baldry, C. Frewer, C. E. Hollingsworth, H. Law, R. C. May, T. M. Smith, F. Stevenson, J. Thomson, and A. Williams were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Ballot having been declared open, the Annual Report of the Council, on the Proceedings of the Institution during the past year, was read. (*Vide* page 163.)

Resolved,—That the Report of the Council be received and approved, that it be referred to the Council to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That the incoming Council be requested to prepare, for the consideration of a Special General Meeting of Members and Associates, such alterations in the Bye-laws as the suggestions contained in the Report with reference to classification may require.

The Telford and Watt Medals, the Telford and Manby Premiums, the Miller Scholarship, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 176 and 177.)

Resolved,—That the thanks of the Institution are justly due and are presented, to the Vice-Presidents and other members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Bateman, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Stephenson, President, for his persevering en-

deavours in the interests of the Institution, for his unremitting attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Stephenson, President, returned thanks.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. William Henry Barry and R. Price Williams, for the comprehensive statement of Receipts and Payments they have prepared; and that Messrs. R. Price Williams and Alfred Rumball be requested to act as Auditors for the ensuing year.

Mr. Price Williams returned thanks.

Resolved,—That the cordial thanks of the Institution be tendered to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their long and valued services to the Institution.

Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected:—

President.

JOHN FREDERIC BATEMAN, F.R.S.

Vice-Presidents.

James Abernethy.	William Henry Barlow, F.R.S.
Sir W. G. Armstrong, C.B., F.R.S.	James Brunlees.

OTHER MEMBERS OF COUNCIL.

Members.

William Baker.	George Fosbery Lyster.
Sir Joseph Wm. Bazalgette, C.B.	William Pole, F.R.S.
Fred. Jos. Bramwell, F.R.S.	Charles William Siemens, F.R.S.
George Barclay Bruce.	David Stevenson, F.R.S.E.
Sir John Coode.	Sir Jos. Whitworth, Bart., F.R.S.
William Froude, M.A., F.R.S.	Edward Woods.

Associates.

Col. Henry Hyde, R.E.	John Peake Knight.
Maj.-General H. Y. D. Scott, R.E., C.B., F.R.S.	

Resolved,—That the thanks of the Meeting be given to Messrs. Baldry, Frewer, Hollingsworth, Law, May, Smith, Stevenson, Thomson, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

ANNUAL REPORT.

SESSION 1877-78.

THE Council, on retiring from office, beg leave to lay before the members a report of the proceedings of the past year, and of the present state of the Corporation. They do so with satisfaction, as the continued prosperity of the Institution testifies that the care bestowed upon it has not been in vain. In one of the earliest Annual Reports, the belief was expressed that the time was fast approaching when a general conviction of the advantage which must result from the periodical meetings of members of the same profession would induce all engineers to unite in advancing the objects of the original projectors. The history of the Society is a gradual realisation of that prospect, and affords abundant evidence of the benefits derived from the association, in one body, of men pursuing different branches of engineering, or connected with engineering operations and pursuits.

THE CONSTITUTION OF THE SOCIETY.

In the Annual Report for 1874 it was remarked that many young professional men, not yet qualified under the Rules for the rank of Member, thought it a hardship to be classified as Associates, a name which did not imply full fellowship, and a class which was composed of persons "not necessarily Engineers." In the subsequent Report for 1875, the Council arrived at the conclusion that it was desirable to create a new class, to distinguish between those engaged in the practice of the profession, as defined in the Charter, and those not so engaged. In the Report for 1876 a scheme was submitted to the Annual Meeting for carrying this plan into effect. The proposal was to establish a new class intermediate between that of Members and that of Associates, and the title Associate-Member was suggested to designate the persons composing it. The members present at that meeting, while otherwise adopting the Report recommending the new class, desired that the title should be left open for future decision. A circular was thereupon addressed to all the Members and Associates, in

order to obtain the opinion of the majority on the subject. About 1,900 copies of this circular were issued, and replies were received from 334 Members and 564 Associates. Of these replies, 418 were in favour of the title "Associate-Member," 182 of "Junior Member," 52 of "Graduate Member," and 66 of "Engineer Associate"—these were the four titles specially mentioned in the circular—while 70 recommended that the designations of the three classes should be Fellow, Member, and Associate respectively; 19 that the simple term Graduate should be adopted for the new class, and the remaining 91 embraced several other propositions. Before, however, the Council could proceed to further action a requisition, signed by 20 Members and 23 Associates, was received, by which it became necessary to summon a Special General Meeting[1] of Members and Associates "to consider the question of the creation of the new class proposed by the Council." The meeting was held on Wednesday, the 25th of April, when it was stated the Council recommended that the members of the new class, by whatever name they might be called, should enjoy all the corporate rights of Members—on which point there had been a reservation in the Annual Report. After considerable discussion a Resolution was passed at the meeting as follows:—

> "That in the opinion of this meeting it is not desirable at present to create any new class of member; but it is desirable that those Associates who are qualified to be Members should take the requisite steps for their transfer."

The Council have therefore continued to act under the existing Bye-laws; and as a result of that meeting, have had under consideration a greater number of proposals for transfer than usual, and have since that meeting had the satisfaction to transfer 58 Associates to the class of Members. Of this number 43 have been effected during the current session.

Thus the main question, to which attention has been so frequently called, the separation of the professional from the non-professional Associates, remains unsettled; and it will in the opinion of this Council be a constant source of embarrassment to their successors in office, until it receives a satisfactory solution.

Under these circumstances, the Council, in the interest of the general body, have come to the conclusion to suggest to the Annual Meeting that in future the Institution shall consist of four

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[1] As the minutes of this meeting have already appeared in the Proceedings, vol. l., p. 59, it is not deemed necessary to repeat them *in extenso*.

classes, namely, Senior Members or Fellows, Members (both classes of Members to enjoy equal corporate rights), Associates, and Honorary Members, and that there shall be a class of Students attached.

Elections and Transfers.

During the past session 2 Honorary Members, 46 Members, and 169 Associates have been elected. The two Honorary Members were their Majesties the King of Portugal and the King of the Belgians. Both have expressed gratification at receiving this mark of distinction, and both have recorded their thanks for the appreciation thus evinced of their endeavours to encourage the progress of Practical Science. The number of Members elected has been greater than in the preceding year, besides which 40 Associates have been transferred to that class. The losses from death and other causes among the Members have been 25, and among the Associates 41, so that there has been an effective increase of 61 Members and 88 Associates. The numbers in each class on the 30th of November, 1877, were:—Honorary Members, 16, Members, 925, and Associates, 1,670, together, 2,611, as against 2,460 at the date of the previous Report.[1]

[1] The tabular statement for the years 1875–76 and 1876–77, of the transfers, elections, deceases, resignations, and erasures of the members of all classes belonging to the Institution, that is, exclusive of the Students, is as follows:—

Year.	Honorary Members.	Members.	Associates.	
1875–76.				
Transferred to Members . .	..	..	20	
Elections	..	34	187	221 − 45 = 176
Deaths	..	13	22	
Resignations	..	..	5	45
Erased from Register . . .	..	..	5	
Members of all Classes on the Books, November 30, 1876.	14	864	1,582	2,460
1876–77.				
Transferred to Members . .	..	..	40	
Elections	2	46	169	217 − 66 = 151
Deaths	..	22	21	
Resignations	..	2	15	66
Erased from Register . . .	..	1	5	
Members of all Classes on the Books, November 30, 1877.	16	925	1,670	2,611

The following deaths were announced during the past year, the bracketed figures after some of the names referring to the volume of "Proceedings" in which memoirs have already been printed:—

MEMBERS: Joseph Armstrong (xlix., 255), Thomas William Armstrong, William Alexander Brooks (l., 172), Arrott Browning, Charles Edward Cawley, *M.P.* (l., 175), William Welham Clarke Edward Dixon, William Thomas Doyne, Osborne Cadwallader Edwards (xlviii., 266), John England, jun., George Giles (l., 177), William Hanson, Robert Hodgson (l., 178), William Johnstone (xlix., 251), Frederick William Kitson, Christopher Bagot Lane (xlviii., 266), Charles Benjamin Le Mesurier, Thomas Page (xlix., 262), Charles Tarrant, Frederick Thomas Turner (l., 181), Edward Wilson, and Henry Winteringham (l., 184).

ASSOCIATES: Edwin Barton (xlix., 265), James Battersby (l., 185), William Beardmore, Thomas Talbot Bury (xlviii., 269), Henry William Churchward, Ardaseer Cursetjee Wadya, *F.R.S.*, Francis Stacker Dutton, *C.M.G.* (xlix., 268), Joseph Fisher, jun. (l., 186), David Forbes (xlix., 270), Robert Wood Everett Green (xlviii., 270), Samuel Hocking, Frederick Hardwicke Johnson, Elias William Jones (l., 186), *Admiral* Sir Stephen Lushington (xlix., 275), James Smith Okell (xlix., 276), the Earl of Orkney (l., 187), Alexander Rhodes (l., 187), Thomas Tenison Ryan (xlviii., 272), Edward Pease Smith, George Albert Twynam, and *Sir* Matthew Digby Wyatt (xlix., 277).

The resignations have been accepted of two Members, Richard Spelman Culley and William Henry Purdon; and of fifteen Associates—John Aiton, Edward Bagot, Edward Pearce Brown, George Osbaldeston Budd, *Admiral* George Evans, William Hay Fea, James Robert France, James Howard, *Lieut.-Col.* Perceval Robert Innes, Alfred Chalmers Lawford, William Naylor, John Sampson Peirce, Robert Sabine, William Thomas Walker, and Edward Orange Wildman Whitehouse.

ADMISSION OF STUDENTS.

The completion of the first decade of the existence of the Student class attached to the Institution affords a convenient opportunity for reviewing the progress made since its foundation. It is with great satisfaction that the Council are enabled to refer to its steady and increasing popularity, as justifying the principles which were originally laid down for its regulation and management, and which have been found to work so well that the experience of ten years has not rendered necessary any modifications. The

Report of 1867 announced the formal establishment of the class in the summer of that year, and stated that 78 candidates had been already admitted in the then current session. Up to 1876 the yearly effective increase did not exceed 37, but the award of the Miller Scholarship seems to have given an impulse to the applications for admission, which in the year named reached 119, the net addition having been 62. Last session 126 candidates were admitted; on the other hand, 35 Students were elected Associates, and 27 withdrew, leaving an effective increase of 64. Out of 823 Students admitted since the 19th of November, 1867, 448 are still on the books (or about 15 per cent. of the gross number of the several classes), 198 have been elected Associates, and 177 have terminated their connection with the Institution.

Contributions to the Funds.

The following statement shows in what manner the amount entered to the credit of Annual Subscriptions, in the Abstract of receipts and payments, was actually obtained:—

Class.	Residents.	Non-Residents.	Totals.	Subscriptions.
				£. s. d.
Members . . .	334	591	925	2,731 11 6
Associates . . .	636	1,034	1,670	4,433 2 0
Honorary Members	8	8	16	0 0 0
Students . . .	171	277	448	799 1 0
Totals . . .	1,149	1,910	3,059	7,963 14 6

To complete this statement it should be mentioned that the Subscriptions outstanding on the 30th of November last were as under:—

Class.	Residents.	Non-Residents.	Totals.	Arrears.
				£. s. d.
Members . . .	14	20	34	122 17 0
Associates . . .	29	42	71	201 12 0
Students . . .	11	16	27	50 18 6
				375 7 6

The Treasurer.

According to the Bye-laws, it is directed that "the Treasurer shall be a Banker in the Metropolis." For many years the account of the Institution has been kept by Messrs. Coutts and Company, whose senior partner has acted as Treasurer. The death of Mr. William Matthew Coulthurst, since the last Annual Meeting, has led to this office being now held by the present senior partner, Mr. Hugh Lindsay Antrobus.

The Meetings and the Publications.

Within the last few years considerable changes have been introduced in the method of conducting the discussions at the Ordinary Meetings. Formerly the Original Communications were read from manuscript, and the discussions were confined to the persons actually present at the meetings, who had no opportunity of becoming acquainted beforehand with the contents of the Papers. The attendance was small, and there was ample time for every one to take part in the proceedings, while but little engineering literature had been accumulated, so that nearly all the facts elicited were novel and worthy of record. Under existing circumstances, the custom of printing a very limited number of proof copies of the Papers before being read, and of circulating them to those supposed to be specially acquainted with the subjects, has led to the communications being criticised by many persons unable to attend the meetings. In this way much useful information, which might otherwise be lost, is collected and included in the "Minutes of Proceedings." In addition, owing to the large number of persons attending the meetings, and who are interested in the subjects brought forward, it often happens that there is not sufficient time for all the intending speakers to join in the debate, and these, too, are permitted to communicate their views in writing through the Secretary. In the past session, one quarter of the printed matter of the discussions, as given in the Proceedings, has been thus derived.

During the past session 12 Papers were read and discussed at the Ordinary Meetings, and 11 other Papers were printed in the "Minutes of Proceedings." Vols. xlvii. to l. (both inclusive) of the series were issued at intervals of about three months, and, as nearly as possible, in the first weeks of February, April, August, and November. The awards to the Authors of 10 of the above referred to 23 Original Communications comprised Watt Medals

and Telford Premiums to William Worby Beaumont and William Cawthorne Unwin, *B.Sc.*; Telford Premiums to Robinson Souttar, Isaac John Mann, William Anderson, John Baldry Redman, Henry Robinson, Alexander McDonnell, and Richard Henry Brunton; and the Manby Premium to Charles Norman Bazalgette.

Now that the fiftieth volume of the Minutes of Proceedings has been completed, it is intended to prepare for publication a General Index, but necessarily abridged, of the contents of the whole series.

The "Abstracts of Papers in Foreign Transactions and Periodicals," forming Sect. III. of the publications, represent as fully and accurately as practicable the foreign engineering literature of the day. The chief results of the management and maintenance of the principal continental and American railways, the improvements of the great American and Indian rivers, details of mining practice, and the statistics of mining and metallurgy prepared by various Governments, have been reproduced in substance. Laborious and valuable experiments on the steam engine, investigations into the theories of steam and heat, have been given from time to time, as they appeared; researches in electricity have been recorded, and the progress of electric lighting has been followed. It is gratifying to find that these labours have been appreciated. The authors of these foreign papers continue to take a lively interest in the proceedings, and to send advance copies of their articles, at times accompanied by a *précis* prepared by themselves. The correspondence received from members also indicates that the Abstracts are more widely read than heretofore. The total number of Abstracts published during the year has been 251, occupying 466 pages, or an average of rather more than $1\frac{3}{4}$ page each. As compared with the previous year, this shows an increase in the number of articles, and a decrease in their length.

Supplemental Meetings for Students were held on eleven Friday evenings, on each of which a Member of the Council presided, and a Paper was read and discussed. The average attendance at these meetings was 30, or 6·7 per cent. on the present number of Students, as compared with 19, or 5·3 per cent., last year, and 24, or 8·0 per cent., the year before last. Altogether 94 students took part in the meetings, about 18 of whom were tolerably constant attendants. Rewards have been granted for seven of the Papers presented last session; the Miller Scholarship for this year having been awarded to Percy Ruskin Allen, for his Paper on "Machine Tools;" and Miller Prizes to Arthur Cameron Hurtzig, Charles Graham Smith, Richard John Gifford Read, Nicholas Watts, William James Chalk, and John Charles Mackay.

As misapprehension has arisen on the subject, the Council take this opportunity of observing that Papers cannot be accepted, in competition for the Miller Scholarship and Miller Prizes, from Students who, before the end of the current session, when the prizes are adjudged, shall have exceeded the limit of age (26 years) when they can remain Students.

The visits of the Students to engineering works in progress were on a more extensive scale than in previous years, and gave the greatest satisfaction to all who could avail themselves of the privileges so courteously accorded.

The Property of the Institution.

The income proper for the year amounted to £9,903 5*s.* 3*d.*, the life compositions and admission fees and Building Fund to £2,113 13*s.*, and the dividends on Trust Funds to £462 16*s.* 6*d.* These several amounts, with the cash balance of £326 11*s.* 7*d.* from last year, and a sum of £25 19*s.* 9*d.* in repayment of certain petty disbursements, make up the total of £12,832 6*s.* 1*d.* on the credit side of the Auditors' statement. Against this there has been an expenditure of £10,278 2*s.*, which may be distributed as follows:—House and establishment charges, £2,091 18*s.* 6*d.*; salaries and wages, £2,431 13*s.* 9*d.*; library, £575 17*s.* 7*d.*; and publications, £5,178 12*s.* 2*d.*; besides payments on account of Trusts of £486 8*s.* 5*d.*, while a sum of £1,726 2*s.* 3*d.* has been invested, and the balance in hand at the end of the financial year was £322 18*s.* 9*d.* The disbursements were thus £374 16*s.* 9*d.* in excess of the income. In regard to the large outlay for "Minutes of Proceedings," it should be explained that at the beginning of 1877 there remained unpaid the accounts for two volumes issued in the preceding session; while on the 30th of November last the Institution was indebted for one volume only, having paid for five volumes in the year. It is hoped that the same plan may be possible in 1878, and that for the future the cost of the publications of each session will be defrayed out of the receipts of the year. Of the sum invested, £129 18*s.* 7*d.* represented the unexpended dividends in 1876 on the Telford and the Miller Funds, and £1,596 3*s.* 8*d.* the capital account of the Institution. In the last Report it was stated that income was indebted to capital in the sum of £208 18*s.* 2*d.*; to this must now be added the difference between the receipts of the year on the latter account, £2,113 13*s.*, and the before-mentioned investment of £1,596 3*s.* 8*d.*; so that there is a balance of £726 7*s.* 6*d.* owing to capital.

The total amount of funded property (including the cash balance) belonging to or under the control of the Institution was last year £37,142 16*s.* 4*d.*; it is now £38,773 4*s.* 11*d.* Of this amount the sum of £14,456 4*s.* 6*d.* represents the various funds held under trusts, and the balance, £24,317 0*s.* 5*d.*, is the absolute property of the Corporation. The securities for these several investments have been inspected by the Auditors, whose signed statement will show that £12,496 3*s.* 4*d.* (being the greater part of the Trust Funds) is placed in 3 per cent. Government stocks, and £25,950 in Debenture stocks, in nearly equal proportions, in eight of the principal railway companies, yielding about 4 per cent.

The broad results thus generally indicated show that financially the Institution is in a sound condition, but that at the same time the income proper is barely sufficient to balance the heavy expenditure entailed in carrying on the objects of the Society as at present liberally interpreted.

[ABSTRACT

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£. s. d.	£. s. d.	£. s. d.
To Balance in the hands of the Treasurer		317 9 7	
— " " " Secretary :—			
Petty cash	3 5 0		
Abstractors	5 17 0	9 2 0	
			326 11 7
— Subscriptions and Fees :—			
Arrears		281 18 6	
Current		7,963 14 6	
Advance		104 1 0	
Life Compositions		233 2 0	
Admission Fees		680 8 0	
			9,263 4 0
— Building Fund			1,200 3 0
— Publication Fund			251 14 0
— Library Fund			102 9 0
— Publications :—Sale of Transactions			266 1 7
— Miscellaneous Receipts			6 5 0
— Dividends: 1 year on			
£. s. d.			
Telford Fund.			
2,839 10 10	Three per Cent. Consols	84 2 8	
2,586 0 11	Three per Cent. Reduced	76 12 2	
2,377 10 5	Three per Cent. Consols (Unexpended Dividends)	70 8 6	
862 14 5	Three per Cent. Reduced (Ditto, ditto)	25 11 4	
			256 14 8
Manby Donation.			
200 0 0	Great Eastern Railway Co., Norfolk, Five per Cent. Preference Stock	..	9 17 6
Miller Fund.			
2,000 0 0	Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	79 0 0	
1,100 0 0	Great Eastern Ditto	43 9 0	
582 18 6	Three per Cent. Consols (Unexpended Dividends)	17 5 4	
1,355 14 11	Three per Cent. Reduced (Ditto, ditto)	40 3 2	
			179 17 6
Howard Bequest.			
551 14 6	New Three per Cents	..	16 6 10
Institution Investments.			
3,650 0 0	Great Eastern Railway Four per Cent. Debenture Stock	144 3 6	
3,000 0 0	London and North Western Ditto	118 10 0	
1,500 0 0	London, Brighton, and South Coast Ditto	59 5 0	
£22,606 4 6	Carried forward	£321 18 6	£11,879 4 8

from the 1ST DEC., 1876, *to the* 30TH NOV., 1877.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street, for Rent, &c.:—						
Repairs	80	9	0			
Rent	650	2	6			
Rates and Taxes	77	13	1			
Insurance	30	6	6			
Furniture	13	11	8			
Oil Painting	300	0	0			
				1,152	2	9
— Salaries				1,700	0	0
— Clerks, Messengers, and Housekeeper				701	13	9
— Donation to late Housekeeper				30	0	0
— Postage and Parcels:—						
Postage	129	13	4			
Parcels	4	6	0			
				133	19	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				351	11	9
— Light, Fuel, &c.:—						
Coal and coke	34	2	6			
Candles	0	3	9			
Oil	0	6	8			
Gas	52	13	6			
Water for engine	6	10	0			
				93	16	5
— Tea and Coffee				39	0	8
— Library:—						
Books	278	3	1			
Periodicals	88	8	10			
Binding	209	5	8			
				575	17	7
— Publication, "Minutes of Proceedings"				5,178	12	2
— Telford Premiums				318	1	10
— Watt Medals				4	15	0
— Manby Premium				12	10	0
— Miller Scholarship				40	0	0
— Miller Prizes				115	16	7
— Diplomas				35	17	3
— Manuscripts, Original Papers, and Drawings				2	16	9
— Annual Dinner (Official Invitations, &c.)				159	19	5
— Winding and Repairing Clocks				3	12	0
— Incidental Expenses:—						
Christmas Gifts	1	15	6			
Assistance at Ordinary Meetings	11	11	6			
Ditto at Students' Meetings	4	2	6			
Beating Carpets and Sweeping Chimneys	0	8	0			
Household Utensils, Repairs, and Expenses	96	10	1			
				114	7	7
Carried forward				£10,764	10	5

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.				£.	s.	d.	£.	s.	d.
£.	s.	d.							
22,606	4	6	Brought forward . .	321	18	6	11,879	4	8
			To Dividends—*cont.*						
			Institution Investments: cont.						
3,000	0	0	North Eastern Railway Four per Cent. Debenture Stock.	118	10	0			
3,000	0	0	Great Northern Ditto . . .	118	10	0			
1,000	0	0	Lancashire and Yorkshire Ditto	39	10	0			
3,000	0	0	Great Western Ditto (1 year on £1,500 and 6 months on £3,000)	88	17	6			
1,500	0	0	London, Brighton, and South Coast Ditto, Four and a Half per Cent. Ditto . .	66	13	2			
3,000	0	0	Manchester, Sheffield, and Lincolnshire Ditto	133	6	2			
1,344	1	8	New Three per Cents . . .	39	16	4			
							927	1	8
£38,450	6	2	Total nominal or par value of Funds.				£12,806	6	4
To Telford premiums :—Repayment of extra cost of binding . .							9	17	0
— Benevolent Fund Petty Disbursements, 1876							16	2	9
							£12,832	6	1

from the 1ST DEC., 1876, *to the* 30TH NOV., 1877.

PAYMENTS—*cont.*

Cr.				£.	s.	d.
Brought forward				10,764	10	5
By Benevolent Fund Petty Disbursements, 1877				18	14	8
— Telford Fund.—Balance of Income not yet expended in Annual Premiums, invested in £21 1*s.* 8*d.*, Three per Cent. Reduced. . .	20	9	6			
— Miller Fund.—Ditto, £112 19*s.* 9*d.*, ditto. . .	109	9	1			
— Institution Investments :—						
£1,500 Great Western Railway Four per Cent. Debenture Stock	1,596	3	8			
				1,726	2	3
— Balance Nov. 30, 1877, viz. :—						
Cash in the hands of the Treasurer . . .	309	11	5			
„ „ Secretary	13	7	4			
				322	18	9
				£12,832	6	1

Examined and found correct.

(Signed) W. H. BARRY, R. PRICE WILLIAMS } *Auditors.*
JAMES FORREST, *Secretary.*

December 3rd, 1877.

PREMIUMS AWARDED.

Session 1876–77.

The Council of The Institution of Civil Engineers have awarded the following Premiums :—

1. A Watt Medal, and a Telford Premium, to William Worby Beaumont, Assoc. Inst. C.E., for his Paper on "The Fracture of Railway Tires."
2. A Watt Medal, and a Telford Premium, to William Cawthorne Unwin,[1] B.Sc., Assoc. Inst. C.E., for his Paper on "The Resistance of Boiler Flues to Collapse."
3. A Telford Premium to Robinson Souttar, for his Paper on "Street Tramways."
4. A Telford Premium to Isaac John Mann, for his Paper on "The Testing of Portland Cement."
5. A Telford Premium to William Anderson, M. Inst. C.E., for his "Experiments and Observations on the Emission of Heat by Hot-water Pipes."
6. A Telford Premium to John Baldry Redman, M. Inst. C.E., for his Paper on "The River Thames."
7. A Telford Premium to Henry Robinson, M. Inst. C.E., for his Paper on "The Transmission of Power to Distances."
8. A Telford Premium to Alexander McDonnell, M. Inst. C.E., for his Paper on "The Repairs and Renewals of Locomotives."
9. A Telford Premium to Richard Henry Brunton, M. Inst. C.E., for his Paper on "The Japan Lights."
10. The Manby Premium to Charles Norman Bazalgette, Barrister-at-Law, for his Paper on "The Sewage Question."

The Council have likewise awarded the following Prizes to Students of the Institution :—

1. The Miller Scholarship to Percy Ruskin Allen, Stud. Inst. C.E., for his Paper on "Machine Tools."

[1] Has previously received a Telford Medal.

2. A Miller Prize to Arthur Cameron Hurtzig, Stud. Inst. C.E., for his Paper on "Submarine Foundations."

3. A Miller Prize to Charles Graham Smith,[1] Stud. Inst. C.E., for his Paper on "The South Reserve Piers and Floating Landing Stage at Birkenhead."

4. A Miller Prize to Richard John Gifford Read, Stud. Inst. C.E., for his "Comparison of the Merits of Wrought-iron Plate and Trussed Girders for Single-span Railway Bridges."

5. A Miller Prize to Nicholas Watts,[1] Stud. Inst. C.E., for his Paper on "Mechanical Puddling in the Manufacture of Iron."

6. A Miller Prize to William James Chalk, Stud. Inst. C.E., for his Paper "On Waves, and on Structures designed to resist their Force."

7. A Miller Prize to John Charles Mackay, Stud. Inst. C.E., for his Paper on "Engineering Explosives."

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[1] Mr. Graham Smith and Mr. Watts have been elected Associates of the Institution since the date of the presentation and reading of their Papers.

SUBJECTS FOR PAPERS.

SESSION 1877–78.

THE COUNCIL of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will be prepared to award Premiums, arising out of special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) now produces about £260 annually.

2. The MANBY DONATION, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings," of the value of £10 a year.

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) now realises nearly £180 per annum. Out of this Fund the Council have established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and are prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to rather more than £16. It is proposed to award this prize every five years, commencing in 1877.

The Council will not, in any case, make an award unless a communication of adequate merit is received; but, on the other hand, more than one Premium will be given, if there are several deserving memoirs on the same subject. In the adjudication of

the Premiums no distinction will be made between essays received from a Member, an Associate, or a Student of the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

LIST.

1. The Triangulation Survey, and Mapping of Countries and Districts, including the Astronomical Observations required for latitude and longitude, and the measurement of bases; with a description of the instruments employed, the reduction of the observations, and degree of accuracy of the results.
2. The Levelling of Countries, either by Spirit-levelling, vertical angles, barometers, or the boiling-point of water; with a description of the instruments employed, the reduction of the observations, and degree of accuracy of the results.
3. The Manufacture of Cements, comparing the processes followed in different countries.
4. The Manufacture of Bricks by Machinery, including descriptions of special kilns, &c.
5. The effect of the lapse of time on the Strength of Materials strained beyond the supposed limit of elasticity, but within the ultimate strength.
6. The Causes of Slips in Rocks and Earths of different kinds, and the Conditions that induce treacherous ground in Railway-cuttings, tunnels, and the sides of valleys near reservoir banks.
7. The Application of Steam Machinery for Excavating, and the Cost as compared with Hand Labour.
8. The Results of the Use of Steel in Mechanism and in works of Construction.
9. The Construction of Warehouses and of other buildings to resist Fire, and the relative merits of stone, brick, iron, and timber for that object.
10. The Warming and Ventilation of large Buildings.
11. The different systems of Road-making best adapted for large Towns, or where the traffic is heavy, including a Comparison of First Cost, Maintenance, and Durability.
12. The Design and Construction of Masonry Dams of great height for retaining water in Reservoirs.
13. The Storage and Filtration of Water, both natural and artificial.

14. The benefits and expedients of Irrigation in India and in other warm climates, and the proper construction of Irrigating Canals, so as to avoid erosion or silting, and to prevent the growth of weeds.
15. The Constant Service of Water Supply, with special reference to its introduction into the Metropolis, in substitution for the Intermittent System.
16. The systems of Domestic Water Supply suitable for rainless districts.
17. The different systems of Opening Bridges, with details of the modes of working them.
18. The Design, generally, of Iron Bridges of very large span, for Railway traffic.
19. The Design and Construction of Dock Gates and Caissons, including the requisite external and internal arrangements, illustrated by recent practical examples.
20. The Design and Construction of Building-slips for large Vessels.
21. The Appliances and Methods used in different countries for Tunnel-driving, Rock-boring, and Blasting, with details of the cost and of the results attained.
22. The Works carried out for the Improvement of the Seine and other French rivers, and of Inland Navigation generally.
23. The relative Value of Upland and of Tidal Waters in maintaining rivers, estuaries and harbours.
24. The Construction of Tide Gauges, and the usual method of carrying out a systematic series of Tidal Observations.
25. The differences in design of British and Foreign Locomotive Engines; showing the benefits derived from increase in weight, and the relation that ought to exist between the diameter of the wheel and the load it has to carry.
26. The Lighting of Railway Carriages.
27. The Construction of Steam Boilers adapted for very High Pressures.
28. The best practical Use of Steam in Steam Engines, and the effects of the various modes of producing Condensation, and of various grades of expansion.
29. The Modern Construction of Marine Engines, having reference to Economy, by Superheating, Surface Condensation, High Pressure, great Expansion, &c.
30. Modern Experience in Screw Propulsion, comprising the comparative efficiency of propellers of large diameter, and of smaller ones deeply immersed, and the influence of form.

31. The best Shapes for Yachts and for Ships for commercial purposes.
32. The relative efficiency of the Screw propeller and Paddle wheels for Towing purposes.
33. A Comparison of the different Modes of transmitting Power for auxiliary purposes on board Ships, and in Shipyards, and Engine Factories.
34. The various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency.
35. The relative advantages of Wind and Water as Motive Powers, compared with Steam Power, and the Motors most suitable for utilising them.
36. Compressed Air as a Motive Power, particularly as applied to Machinery in Mines and to Locomotives in Tunnels, with some account of its application on the Continent.
37. The Manufacture of Mineral Oils, and the Lamps best adapted for their consumption in dwellings and lighthouses.
38. The 'Output' of Coal in the United Kingdom, as compared with that of other countries, illustrated by statistics, showing where Coal is produced, where and how it is consumed, and the relative quantities exported.
39. The Methods and Machinery employed in sinking and in working deep Coal Mines.
40. Coal Depôts for Ocean Steamers, the various points involved in their management, and the methods of preserving large quantities of coal from deterioration.
41. The Metalliferous or other Mining Districts in different countries, and the mode adopted in working them.
42. The Methods employed in securing the Excavations in mining large and irregular-shaped mineral deposits, for example, the Almaden Mines, the Great Comstock Lode, &c.
43. The appliances used in different countries for Dressing the Ores of Lead, Copper, Zinc, and Tin, and the Smelting of such Ores, with details of the results and cost by various methods.
44. The losses in the Reduction of Metallic Ores by different methods, distinguishing losses in dressing from those in smelting.
45. The disposal and utilisation of Slags from various smelting processes.
46. The Management of Underground Waters in mining districts, and the relative economy of distributed or trunk pumping engines, adits, &c., in particular cases.

47. The Appliances and Processes for the manufacture of Artificial Fuel in different counties.
48 On recent Progress in Telegraphy, with a notice of the theoretical and practical data on which that progress has been based.
49. Electricity as applied to Lighting purposes.
50. On Torpedoes, and their influence on Naval Construction.

Instructions for Preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by a concise Abstract.

All Communications should be accompanied with a set of drawings on tracing paper, to as small a scale as is consistent with distinctness, and ready to be engraved. If accepted for reading then there will be required a series of Diagrams (which will be returned) sufficiently large and boldly coloured, so as to be clearly visible when suspended in the Theatre of the Institution.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The Communications must be forwarded to the house of the Institution, where any further information may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, London, S.W.*
October, 1877.

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1ST, 1876, AND NOVEMBER 30TH, 1877.

AUTHORS.

Armstrong, Sir W. G. No. 1,524.—The History of the Modern Development of Water Pressure Machinery. With a series of Diagrams. (Minutes of Proceedings, vol. l., p. 64.)

Avern, F. M. No. 1,528.—Account of the Construction of the Railway Bridge over the River Jhelum. With 11 Drawings and 6 Photographs.

Aydon, H. No. 1,514.—Liquid Fuel. With a series of Drawings.

Barron, F. C. No. 1,512.—Description of the Works constructed by the Bilbao Iron Ore Company in Spain. With 8 Drawings (*post*, p. 237).

Bazalgette, C. Norman. No. 1,506.—The Sewage Question (xlviii. 105).

Carson, W. No. 1,533.—Egremont Ferry Landing. With 2 Drawings.

Craig, W. Y. No. 1,541.—Fires in Coal Mines.

Davey, H. No. 1,551*.—Direct-Acting, or Non-Rotative, Pumping Engines and Pumps. With 11 Drawings.

Doherty, W. J. No. 1,523.—Description of Cofferdams used at Dublin, Birkenhead, and Hull. With 5 Drawings (*ante*).

Haycraft, G. No. 1,519.—On an Economical Method of Manufacturing Charcoal for Gunpowder. With 1 Drawing (l. 105).

Head, J. No. 1,504.—On the Combustion of Refuse Vegetable Matter, such as Straw, Reeds, Cotton Stalks, Brushwood, &c., under Steam Boilers. With 10 Drawings (xlviii. 75).

Herschel, C. No. 1,535.—On the Erosive and Abrading Power of Water on the sides and bottoms of Rivers and Canals.

Higgs, R. W. H. P., and Brittle, J. R. No. 1,545.—Some recent Improvements in Dynamo-Electric Apparatus.

Holt, A. No. 1,511.—Review of the Progress of Steam Shipping during the last Quarter of a Century (*ante*).

Hull, E. No. 1,505.—On a Deep Boring for Coal at Scarle, Lincolnshire; and its bearing on the question of the Easterly Limit of the Yorkshire Coal Measures beneath the newer Formations. With 1 Drawing (xlix. 160).

AUTHORS.

Jenkinson, C. H. G. No. 1,548.—The Denver and Rio Grande Railway, and the Railways of the Rocky Mountains. With 3 Drawings.

Knowles, Sir F. C., Bart. No. 1,542.—Notes upon the Law of Resistance to surfaces of Bodies moving in incompressible Fluids.

Leslie, B. No. 1,544.—The Hooghly Bridge. With 5 Drawings.

Longridge, J. A. No. 1,534.—On the Evaporative Power of Locomotive Boilers.

Mackenzie, J. B. No. 1,547.—Avonmouth Dock.

McAlpine, W. J. No. 1,540.—The Foundations of the New Capitol at Albany, New York. With 2 Drawings.

O'Connell, Col. P. P. L. No. 1509.—Approximate Solution of the Drainage Problem.

Perram, G. J. No. 1529.—On the Tank Restorations and Repairs being carried out by the Public Works Department in the Tank District of the Cauvery Division. With a series of Diagrams.

Pickwell, R. No. 1,515.—The Encroachments of the Sea from Spurn Point to Flamborough Head; and the Works executed to prevent the Loss of Land. With 7 Drawings (*post*, p. 191).

Price, J. No. 1,537.—Movable Bridges.

Shakespear, Lieut.-Col. J. D. No. 1,521.—The Shakespear Lamp.

Souttar, R. No. 1,518.—Street Tramways. With 6 Drawings (l. 1).

Stooke, T. S. No. 1,516.—The Whiston Pumping Station, St. Helen's, Lancashire. With 3 Drawings (xlix. 221).

Weedon, J. F. No. 1,543.—The Queensland Railways; with some Remarks upon their future Development. With 9 Drawings.

Whitley, H. M. No. 1,538.—Results of the Working of a Steam Excavator on the Castle Eden and Stockton Railway.

Wilson, G. No. 1,551.—Irrigation in the South of France; Department of the Bouches-du-Rhône. With 3 Drawings (*post*, p. 213).

Wragge, E. No. 1,508.—Canadian Narrow-Gauge Railways (xlviii. 252).

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Also, the Proprietors of the various Journals and Periodicals enumerated in the Appendix to the last Annual Report.

The Subscriptions to the Library Fund were as follows:—

	£.	s.	d.
Baggallay, H. C.	5	5	0
Bailey, Wilfred	1	11	6
Blandy, A. F.	10	10	0
Cartmell, J. R.	1	1	0
Currey, Charles	7	7	0
Dawson, J. H.	5	0	0
Denny, P.	5	5	0
Downing, S. F.	1	1	0
Kitson, James, Jun.	5	5	0
Lundie, G. A.	1	1	0
Murray, Alex.	2	12	6
Napier, John	31	15	0
Peel, W.	1	1	0
Rundall, J. W.	5	0	0
Shortt, C. H.	1	1	0
Simpson, E. T.	4	0	0
Smith, T. Taylor	5	5	0
Story, J. Somes	3	3	0
Tomlison, H.	3	3	0
Wild, J. H.	2	2	0
Total as per Cash Statement	102	9	0

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SECT. II.—OTHER SELECTED PAPERS.

No. 1,515.—"The Encroachments of the Sea from Spurn Point to Flamboro' Head, and the Works executed to prevent the Loss of Land." By ROBERT PICKWELL, Assoc. Inst. C.E.

THE Author believes that an account of the ceaseless loss of land going on along this part of the coast of Yorkshire, of its geological formation, and of the works constructed as defences, some of which have been carried out under his personal direction, may prove of interest to the Institution. The subject bears, to some extent, upon the vexed question of the source of the enormous amount of alluvium in suspension in the waters of the Humber, which is so great a difficulty in dealing with the improvement of the navigable channels of the estuary. There is another question upon which this subject also bears, namely, the possible ultimate outflanking and destruction of the Spurn neck and lighthouses, and the consequent loss of the great harbour of refuge in the Humber. In order to give reliable facts and data, the Author made a personal survey of the coast from Spurn Point to Flamboro' Head, examined all the old plans of the district upon which reliance could be placed, and took careful measurements and notes in each parish along the coast.

The communication may be divided as follows:—

1. An account of the loss of land along the coast from early times down to the present from actual admeasurement.
2. An account of the engineering works to resist the inroads of the sea, with their relative cost, &c.
3. The Author's view of the effect of this waste of coast upon the navigation of the Humber.

1. AN ACCOUNT OF THE LOSS OF LAND ALONG THE COAST FROM EARLY TIMES TO THE PRESENT. (Plate 4).

This subject has already been alluded to in communications by Mr. Oldham, M. Inst. C.E.,[1] and by Mr. Shelford, M. Inst. C.E.[2] Smeaton, in his "Narrative of the Building of the Eddystone

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 454.
[2] *Ibid.*, vol. xxviii., p. 472.

Lighthouse," put the loss at 10 yards per annum. Mr. Oldham, in evidence before a Select Committee of the House of Lords on the Holderness Embankment and Reclamation Bill, April 1866, chap. 360, p. 20, reckons it at 2¼ yards, Mr. Shelford at 2¼ yards per annum, and the "North Sea Pilot" states it to be 10 feet per annum. The Author believes that the loss named in the above papers, though correct for a limited locality, and at the time when the measurements were taken, cannot represent the loss along the entire coast.

Although Spurn Point does not strictly come within the subject of the wasting cliffs, it may fairly claim attention. This long, spoon-like neck, projecting from the mainland at Kilnsea for 2 miles southward into the Humber, is entirely formed of shingle and sand, through which the sea percolates freely. About the year 1860 a boring was made in the lighthouse, and nothing but shingle was found at a depth of 50 to 60 feet; the water rose and fell with the tide, and corresponded nearly with the sea both in level and taste. "Ravenser" was situated here and on the mainland; for in Kirby's Inquest, 1295, it is stated that "The heirs of Ingram de Risum hold in Ravenser 2 carucates (240 acres), where 48 carucates make a knight's fee." Mr. Shelford has stated the known movements of Spurn Point southwards and westwards to 1864.[3] The Author's measurements in September 1875 show a further southward extension of 60 yards since 1864, or 5·4 yards per annum, while the movement westward has been arrested. Since 1864 there has been a gain of land extending eastward, due to the joint effect of the prohibition by the Board of Trade of the removal of shingle from the beach, and of the groynes built by Sir John Coode, M. Inst. C.E. There has been no waste at the High Lighthouse from 1869-70 to 1875, the gain of land eastward along the entire length of the neck varying from 30 to 80 yards in width, or an average of 6 yards per annum. The material is composed of shingle and drift sand, in many places 8 to 10 feet above high water spring tides, grown over with mat grass.

Proceeding northward, the mainland is first met with at Kilnsea. Here the boulder clay sinks low, and the drift is exposed to the action of the waves. Hence, at this and similar depressed cliffs, the sea has made greater inroads than on higher cliffs, where the boulder clay forms a strong natural revetment wall at their foot. The loss at this point has been great. In Doomsday, 1080, Morcar had 13½ carucates of land to be taxed, or 1,620

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 480.

acres. In 1852 the extent of Kilnsea was only 911 acres, giving a total loss of 709 acres since 1080. This, with the present frontage to the sea taken as an average, gives a width of 1,950 yards washed away in seven hundred and seventy-two years, or 2·5 yards per annum. In 1766 the chancel of Kilnsea Church was 95 yards from the cliff; in 1833 only 4 yards of the west end of the church were standing, so that, allowing 30 yards as the length of the church, there had been a waste of 120 yards in sixty-seven years, or 1·8 yard per annum. From 1833 to 1847 the average loss was 5 yards per annum, and the whole of Kilnsea has been destroyed during the last century. The "Blue Bell" in New Kilnsea has a stone built into its east wall, inscribed, "Built in year 1847; distance from sea 534 yards." In September 1876 it was 392 yards from the sea, so that the loss has been 5 yards per annum. At the north end of the parish, Mr. Tennison's farmhouse is 242 yards from the cliff, the loss since 1840 having been 5·3 yards per annum. The parish has lost 220 acres, including the entire village and church, since 1818, which if the land be valued at £50 per acre, gives a loss of £11,000. It has been necessary from time to time to construct at this place embankments across the depression in the cliffs, to prevent the flood tides inundating an extensive area of cultivated land.

The same irregularity in the loss appears at Easington, where the boulder clay sinks below high water. On the Author's recommendation, and for future reference, a stone was built into the east wall of Mount Pleasant Cottage, at the east end of Easington, to indicate that in 1876 the cliff was 616 yards distant due east. In 1771 the same point was 880 yards distant, and up to 1852 the annual loss was 1·8 yard per annum; from 1852 to 1876 it was 5 yards per annum. North of the village another depression occurs in the cliff, and the sea has scooped out a bay 300 yards across the mouth, and 40 to 50 yards broad. Easington Church in 1771 was 1,056 yards from the cliff; in 1833 this distance had been reduced to 968 yards, causing a loss of 1·4 yard per annum; and from that time up to 1852 the loss was 1·4 yard per annum. In 1876 the distance of the church from the cliff was 861 yards, the encroachment having been at the rate of 3·3 yards per annum.

At about 1 mile north of the village is the manor of Dimlington. Here the cliffs rise to a height of 60 feet at the south end. According to Doomsday, "In Dimelton there are 5 carucates of land to be taxed," equal to 600 acres, "value in King Edward's time thirty-two pounds, now eight pounds," or £652, now £163. Here certain monks of Meaux Abbey lost 55 acres between 1291

and 1396. The waste opposite Dimlington Farmhouse has been as follows:—From 1771 to 1852 it was 1·8 yard per annum. In 1876 the distance from the cliff was 194 yards, giving a loss of 5·1 yards per annum. From this point the cliff rises, and at "Dimlington High Lands" attains an elevation of about 110 feet, with 15 to 20 feet thickness of boulder clay at the base. From here the cliffs gradually become lower, and at Outnewton they are from 60 to 70 feet in height. Near the alleged site of the old manor Garth are the ruins of the old chapel. The loss opposite this ruin from 1771 to 1852 was only 0·8 yard of land per annum. In 1876 the ruin was 60 yards distant from the cliff, the loss since 1852 having been 3 yards per annum. The distance of the north-east wall of the cart shed of this farm is 184 yards from the cliff.

At the gorge, separating the parishes of Outnewton and Holmpton, the rate of encroachment by the sea from 1802 to 1852 was 0·9 yard, and from 1852 to 1876 3·5 yards per annum.

The cliffs at Holmpton are about 30 feet high. From Holmpton Church the distance to the cliff in 1786 was 1,200 yards, the loss up to 1802 being 0·5 yard per annum. From that date up to 1833 the loss was 2 yards per annum; then to 1852 it was 0·3 yard per annum; and in 1876 the distance was 1,050 yards, the loss having been more than 3 yards per annum.

The parish of Withernsea has a sea frontage of 2½ miles, and has suffered much; the cliffs are from 10 to 25 feet in height at the south end of the parish. Opposite "Nevilles" farmhouse, from 1794 to 1852, the waste was 0·7 yard per annum. In 1876 the distance from the cliff was 375 yards, the waste having been 2·3 yards per annum. Half a mile farther north the "Intack" farm in 1876 was 220 yards from the cliff. Between 1833 and 1852 the loss of land was 2·4 yards per annum; and since then it has been at the rate of 2 yards per annum. At the village of Withernsea, where only half-a-dozen of the old cottages remain, opposite the southernmost house of the old village on the east side of the high-road, from 1794 to 1852, the loss was 1·1 yard of land per annum. The distance of the house from the cliff in 1876 was 455 yards, and the loss of land had been 145 yards in the twenty-four years, or at the rate of 6 yards per annum. A little north of this are the poor-houses, standing back to the east of the road. Opposite these, from 1794 to 1852, the loss was only 0·5 yard per annum; but the distance from the cliff in 1876 was only 290 yards, the loss having been 135 yards in twenty-four years, or 5·6 yards per annum. Opposite the church the loss from 1794 to 1833 was 1·15 yard per annum; from 1833 to 1852 it was 2 yards per annum,

and in 1871 the distance from the cliff was 315 yards, the loss having been 3·6 yards per annum. Opposite the east end of the old house close to Queen's Terrace, from 1794 to 1852 the loss was 1·2 yard per annum; and in 1871, when the distance from the cliff was 216 yards, the loss had been 4·2 yards per annum. The present watering-place of Withernsea is situated in both Withernsea and Owthorne parishes, and here the cliff disappears below high-water level.

At Owthorne the loss has been similar to that at Withernsea. In 1786 the sea reached the wall of the churchyard, and in 1816, a storm carried a large part of the edifice down the cliff. Almost the last of the tower was gone in 1822. Taking the church to have been 30 yards in length, the waste from 1786 to 1822 was 1·2 yard per annum. The sea gained 70 yards more up to 1852, or 2·3 yards per annum, and an additional breadth of 48 yards up to 1868, or 3 yards per annum. Opposite the east side of the butcher's shop at the corner of the Hull Road, the loss from 1812 to 1852 was 105 yards, or 2·6 yards per annum. Subsequently, up to 1868, a breadth of 46 yards more was lost, or 3 yards per annum. Near the chapel of ease, opposite the west side of the high-road, the loss from 1812 to 1852 was 2·2 yards per annum; then up to 1868 it was 3·3 yards per annum. The distance of the road from the cliff in 1871 was 78 yards, the loss in the intermediate three years having been 3·3 yards per annum. The loss at the farm just outside the village, at the corner of the Tunstall Road, was from 1812 to 1852 71 yards, or 2 yards per annum. In 1871 the distance of the corner of the road from the cliff was reduced to 30 yards, the loss in the interim having been at the rate of 2 yards per annum.

At Withernsea and Owthorne the degradation of the cliff has been arrested by groynes and other defences, put down by the Author in 1870 for the Withernsea Pier, Promenade, and General Improvement Company. Since that date there has been practically no loss of land.

At Waxholme the cliffs are 30 to 35 feet high. At the northern farm the loss of land from 1844 to 1852 was at the rate of 2·6 yards per annum. In 1876 the distance was 92 yards from the south-east corner of the east barn to the cliff. A breadth of 41 yards has been lost during the last twenty-four years, or 1·7 yard per annum.

At Newsam another manor has been lost in the sea, as from Doomsday, "In Ninuehusum Ernwin had 5 carucates of land and 2 oxgangs to be taxed," or at least 600 acres. There is

nothing of this land left now. The loss at the coastguard station, opposite the east end of the rocket apparatus shed, has been from 1844 to 1852 at the rate of 1·2 yard per annum. In 1876 the cliff was 26 yards distant, showing a further loss of 1·7 yard per annum. North of the station is Sand-le-Mere, a dried fresh-water lake with an embankment constructed on its sea face of sand overgrown with bents.

At the village of Tunstall the cliffs are from 35 to 40 feet high, having a base of 15 feet in height of boulder clay. Opposite the east side of Seaside Lane, running parallel with the cliff, the loss from 1777 to 1852 was 1·1 yard per annum. The distance of the lane from the cliff in 1876 was 145 yards, indicating an encroachment of 1·6 yard per annum. Opposite the church, from 1786 to 1833 the loss was 3·4 yards per annum; then up to 1852 a further loss of 0·7 yard per annum occurred; and in 1876 the distance from the cliff was 710 yards, showing a further loss of 1·7 yard per annum.

Monkewike has been almost all lost in the sea. According to Doomsday it contained "2 carucates of land," or 240 acres; now almost all is gone.

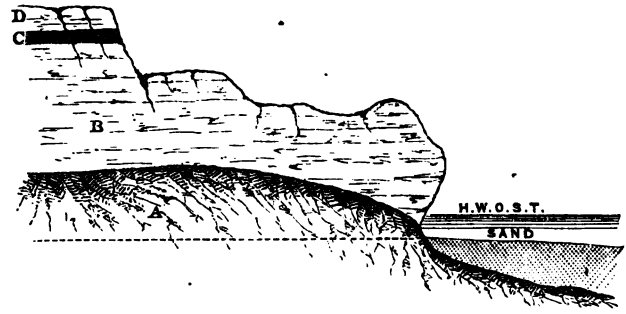
Opposite Hilston Church, from 1777 to 1852 the loss was 1·1 yard per annum. In 1876 the distance of the church from the cliff was 1,073 yards, the loss in the meantime having been 1·4 yard per annum. The cliffs here are about 60 feet high, with a stratum of from 15 to 20 feet of boulder clay at the base. Opposite "Hilston Mount," or "Admiral Storr's Towers," from 1832 to 1852 the loss of land was 1 yard per annum; and in 1876 the distance from the cliff was only 1,140 yards, the loss in the interim having been at the rate of 1·66 yard per annum.

The waste of these cliffs is not by any means regular, or even gradual, but occurs at intervals in huge landslips, 200 to 600 yards long, and from 20 to 50 yards in width; after which there is generally no more loss at these points for three or four years, until the looser material of the slip itself and the base on which it had rested have been washed away, leaving the cliff face proper exposed. In time the waves undermine the foot, and by the aid of frost and land water bring down fresh slips. Figs. 1 and 2 represent two landslips at this point of the cliff. The base A, of boulder clay, stands up as a revetment wall almost perpendicular for 20 feet in height; B is the old drift of sand, gravel, clay, &c.; at C is a fresh-water deposit, 60 to 65 feet above the sea-level, about 5 inches deep; and D is the "new drift," or surface covering.

In Doomsday, Grimston is stated to contain 6 carucates of land,

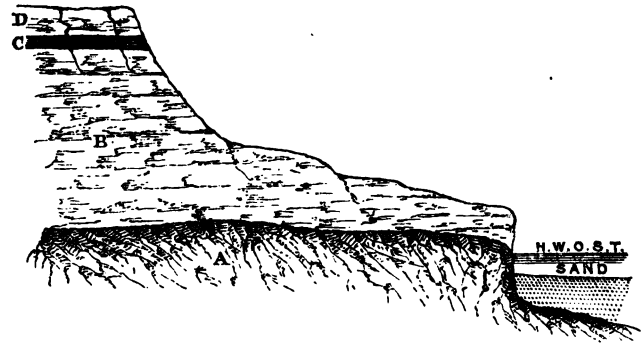
or 720 acres; according to the survey of 1782 it only contained 275 acres, the loss of land having been 445 acres in seven hundred years. Opposite the present Grimston Hall, from 1833 to 1852 the loss was at the rate of 1·3 yard per annum. In 1876 the distance of the hall from the cliff was 675 yards, 25 yards having been lost

FIG. 1.



in twenty-four years. Opposite the farmhouse, on the site of part of the ancient Grimston Garth, the seat of the Grimstons since the Conquest, the loss from 1833 to 1852 was 1·3 yard per annum. In 1876 the distance of the farmhouse from the cliff was 240 yards, the encroachment of the sea in the interval having been 60 yards,

FIG. 2.

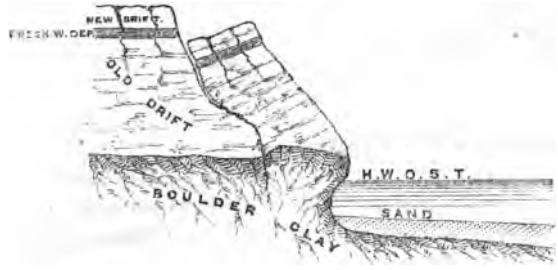


or 2·5 yards per annum. Here, again, the cliffs are about 70 feet in height, and exhibit landslips in different stages of progress. Fig. 3, a sketch of one of the slips in an early stage, shows how the sea, after clearing away all remains of the preceding slip, acts at the foot of the boulder clay base, undermining it until the superincumbent earth eventually breaks away and slides gradually

down to the foot. This description of slip occurs when the beach is unusually low, and admits of deep water at the cliff foot.

"Ringborough," at the south end of the parish of East Newton, has suffered much; the cliffs are about 45 to 50 feet high. Opposite the west end of this farmhouse, from 1833 to 1845 the loss of land was 0·7 yard per annum; from that date up to 1852 the loss

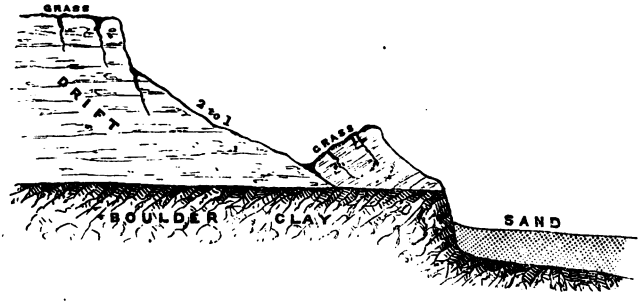
FIG. 3.



was 3 yards per annum; and in 1876, when the distance of the farmhouse from the cliff was 207 yards, a breadth of 70 yards had been lost in twenty-four years.

"Thorp," which according to Doomsday contained 5 carucates and 6 oxgangs of land, or 690 acres, is now reduced to about 148 acres, the loss having been 540 acres in seven hundred years. Fig. 4 shows another landslip at this point in a more advanced

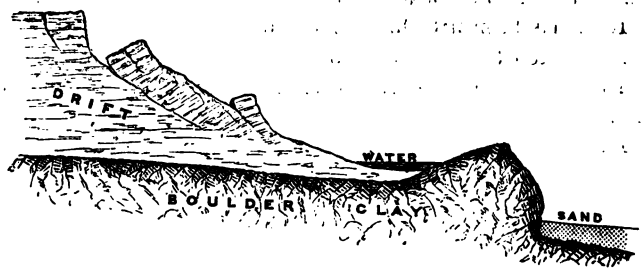
FIG. 4.



stage of progress, with only a small portion of the material of the original slip left upon the ledge of boulder clay. This slip is from 50 to 60 yards long and 30 yards wide. It is probably two or three years old, and will soon be cleared off, to be followed by a steep undermined cliff face and an ultimate heavy slip. At the north end of this parish the cliffs are still about 70 feet high, and

present slips in various stages of progress. Fig. 5 shows one such slip, 300 yards in length and from 40 to 50 yards in width. This

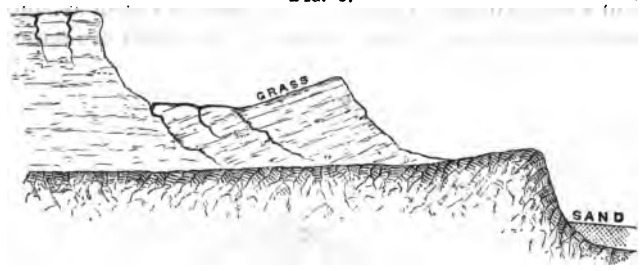
FIG. 5.



is an old slip with a very tough foot of boulder clay. Fig. 6 is a sketch of another slip of more recent occurrence, although not by any means new; this is about 200 yards in length, where the cliff is 70 feet high.

The cliffs at Aldborough are about 70 feet high, and at the present time are suffering very much from landslips. Indeed, almost the whole length of the cliff in this parish may be regarded as one huge landslip from end to end. At the south end of the parish there is a landslip 900 yards in length, and from 50 to 60

FIG. 6.



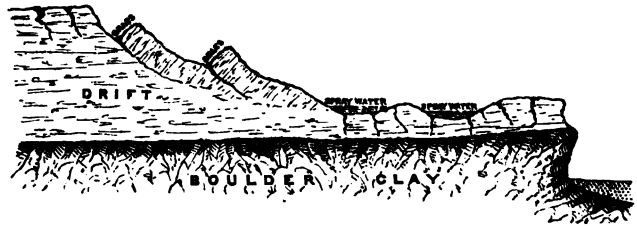
yards in width; and here it will be noticed (Figs. 7 and 8) how the back water of the storm waves, breaking up the foot of the cliff, draws down the slope of the cliff into a succession of slips, which eventually are washed completely off the ledge of boulder clay. The land springs are the chief cause. In this parish the site of the old church is now far out to sea; but the present church, in 1786, was 2,043¾ yards distant from the cliff, the loss being, up to 1832, 2 yards per annum; a further loss of 23 yards was incurred up to 1852; and in 1876 the distance was 1,890 yards the rate of degradation having been 1·7 yard per annum.

Great Colden is close to the edge of the cliff, here about 35 feet high. From 1764 to 1833 the loss opposite the nearest farmhouse to the cliff was 1·3 yard per annum. Opposite the old house within the ancient moat, near the Cross Keys public-house, the loss of land since 1852 has been 2·8 yards per annum.

At Mappleton the cliffs are about 50 feet high. The total loss of land from 1786 to 1874 has been 206 yards, or 2·3 yards per annum.

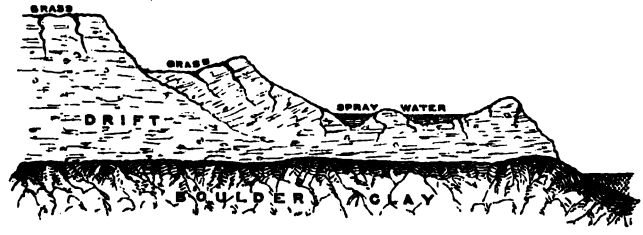
At Hornsea Burton the cliffs are from 30 to 40 feet high. By

FIG. 7.



Kirby's Inquest the "heirs of Gilbert de Mapleton" held here 6 carucates of land, or 720 acres. The area in 1852 was reduced to 409 acres, showing a loss of 311 acres. Taking the present sea frontage of 1,400 yards to be an average of that lost, the above is equal to a screed of land 1,075 yards in breadth lost in five hundred and seventy-one years. By an inquest held in 1400, it appears that

FIG. 8.



between the years 1334 and 1400 the Abbey of Meaux lost 27 acres of land. Opposite the brick-yard cottage at the south end of Hornsea Burton, from 1845 to 1852 the loss was 11 yards; and from 1852 to 1876 it was 1·4 yard per annum. Opposite the east side of Hornsea Burton farmhouse, from 1845 to 1852 the loss of land was 6 yards. In 1876 the distance of the house from the cliff was 208 yards, indicating a loss of 1·3 yard per annum. Oppo-

site Hornsea, another depression in the cliffs is the site of an ancient fresh-water lake. Hornsea Beck, a hamlet anciently close to the present Hornsea, stood about 500 to 600 yards beyond the existing cliff. The loss here and at Hornsea was the subject of early investigation. At an "Inquisition held at Hornsea, on the 28th of April, 1609, 7 James I.," "George Fenwick, Gent., John Goldwell, Gent., and eighteen of the yeomanry made oath to this effect: We find decayed by the flowing of the sea in Hornsea Beck, since the first year of King Edward VI., 1546, thirty-eight houses and as many little closes adjoining. Also we find, since the same time, decayed in ground the breadth of twelve score yards throughout the fields of Hornsea" (or 4 yards per annum). In this inquiry, John Galloway, of Hornsea, said that "there doth usually every year waste the breadth of 40 feet, which is more than heretofore." This statement is referring to the loss after the destruction of the pier at Hornsea. "Ed. Harrison, aged eighty, also said that he has known 300 yards washed away; and that there was a peere at Hornsey Beck, during the continuance whereof the decay was very little." From measurements made by a Mr. John Harrison, in 1757 and 1759, it appears that the loss was 11 yards 4 inches in one year and five months. The house from which the above measurements were taken was washed away in 1785. This house in 1759 was 50 yards distant from the cliff which indicates a loss of 2 yards per annum. Opposite the church, from 1786 to 1836 the loss was 2·7 yards per annum. Then up to 1852 the loss was 2·1 yards per annum; and in 1876 the distance to the then high-water mark was 930 yards, showing a loss of 1·5 yard per annum. These measurements were taken opposite the low lands at Hornsea Gap, there being no cliff, and are consequently only approximate, as the high-water mark varies with the state of weather and amount of beach. Opposite the road running east and west, and immediately south of the Marine Hotel, from the east side of its junction or cross-road with the north and south road, from 1809 to 1852 the loss of ground was 2 yards per annum. In 1876 the same point was only 283 yards from the cliff, the loss having been 1·8 yard per annum. The loss at the boundary of Hornsea Burton and Hornsea close to Stream Dyke running through Hornsea Gap, from 1809 to 1845 was 88 yards, equal to nearly 2·5 yards per annum; and from 1845 to 1876 the loss of ground was 55 yards, or 1·8 yard per annum. At the northern end of Cliff Lane, which runs north of Hornsea nearly up to Atwick parish, opposite the east fence of the lane, from 1809 to 1852 the loss was 2·7 yards

per annum. In 1876 the distance of the fence from the cliff was 167 yards, the loss of land in the interval having been 2·1 yards per annum.

At Atwick the cliffs are from 30 to 35 feet high. At the south end of Long Lane, situated between the village, the cliff, and opposite the east fence of the same, the loss from 1769 to 1852 was 2·1 yards per annum. In 1876 the distance was 242 yards, indicating a loss of 24 yards in twenty-four years. In this parish there is an ancient stone cross on the village green. It is stated in "Pol. Hist. Holderness" that "As lately as the year 1786 the cross was distant from the sea 33 chains 61 links. It is now scarcely half that distance." This statement should be received with caution, and must be incorrect, as the Author found that as lately as 1852 this cross was 37·50 chains, or 825 yards from the cliff, and that in 1769 it was 1,012 yards, showing a loss of 2·25 yards per annum; and in 1876 the distance was 800 yards, or 25 yards lost in twenty-four years.

Skirlington, in Atwick, is a little north of the latter, and is returned in Doomsday as containing 5 carucates of land, or 600 acres. The area in 1756 was 335 acres, and in 1852 only 328 acres. The total loss since 1080 appears to have been 272 acres. Taking the present sea frontage to represent that already washed away, these quantities give a total loss of 2,500 to 3,000 yards in breadth in eight hundred years. The actual loss of land from 1769 to 1852 was 1·9 yard per annum. Between 1852 and 1876 the total loss was 36 yards.

At Skipsea the cliffs are from 30 to 35 feet high, with a fresh-water valley between them running inland. South-east of Skipsea village is the site of the ancient hamlet of Cleton, or Clayton, now lost in the sea. Opposite the east side of Cliff Lane, from 1765 to 1852 the breadth of land lost was 172 yards. In 1876 the distance of Cliff Lane from the cliff was 124 yards, indicating a further loss of 34 yards in twenty-four years. A little farther south is a low fresh-water peat valley, called "Withow Hole," the site of the ancient hamlet of Withow, now lost in the sea. The peat bed is 150 yards long, with fresh-water sediment 5 to 7 inches thick, and peat 1 to 2 feet thick. To the north of this point, and directly east of Skipsea, stood the ancient village of Hyth, or Hyde, also lost in the sea. According to the chronicle of the Abbey of Meaux, it was totally destroyed as early as 1396. Opposite the west end of the cottage in Cliff Lane, situated two fields north of the road from Skipsea to the sea, from 1765 to 1852 the loss of land was 183 yards. In 1876 the distance of the cottage

from the cliff was 165 yards, indicating a further loss of 18 yards in twenty-four years.

Farther north, just within the parish of Ulrome, is a farmhouse south of that known as "Sea Breezes." The loss of land here from 1765 to 1852 was at the rate of 1·3 yard per annum. The distance from the east face of the house to the cliff in 1876 was 153 yards, showing an additional loss of 27 yards in twenty-four years. At Ulrome the cliffs are from 10 to 20 feet high, the boulder clay occasionally disappearing altogether. The loss of land at the coastguard station from 1766 to 1852 was 0·8 yard per annum; from 1852 to 1876 the loss was 1·5 yard per annum. At the north of the parish, near the Barmston Drain, the loss of ground from 1756 to 1766 was 40 yards, or 4 yards per annum; from 1766 to 1852 an additional breadth of 35 yards of land was lost, while from 1852 to 1876 the loss was 2·7 yards per annum. The east side of the wooden horse-bridge across the Barmston Drain being 230 yards distant from the cliff in 1876.

At the south end of the parish of Barmston, the loss from 1756 to 1852 was 87 yards; and from 1852 to 1876 the loss was 2 yards per annum. North of this parish stood the ancient village of Hartburn, now lost in the sea. At this point the loss of land from 1756 to 1852 was 66 yards, and from 1852 to 1876 it was 14 yards.

The township of Auburn has almost all been lost, the ancient village bearing the same name having been entirely washed away.

Wilsthorpe is another small township, of which the village of the same name has also been entirely lost in the sea.

At Hilderthorpe the cliffs are from 25 to 30 feet high, and they contain large quantities of chalk drift. A little north of the village the loss of land from 1805 to 1852 was 2·1 yards per annum. In front of Colonel Rhode's estate the loss from 1852 to 1872 has been computed at 2·2 yards per annum. Immediately to the south of the Bridlington Quay South Pier the loss of ground from 1805 to 1852 was 2 yards per annum, and from 1852 to 1872 it increased to 3·5 yards per annum. Bridlington Quay (of which Hilderthorpe forms part) has suffered little in actual loss since the erection of the harbour and pier works, and the masonry and timber promenades along the edge of the cliff. Immediately to the north of the North Pier, the cliffs have been protected by the pier, causing an accumulation of beach. The loss opposite Fort Hall from 1771 to 1852 was 0·4 yard per annum. The loss of ground at Sands Cut, the boundary of Bridlington and Sewerby parishes, from 1771 to 1852 was only 45 yards.

At the south of the parish of Sewerby, opposite the east end of

Sands Cottage, from 1802 up to 1852 the loss of land was 35 yards. In 1877 the distance of Sands Cottage from the cliff was 14 yards, indicating a loss of more than 0·6 yard per annum. At Potter's Hill the breadth of ground lost from 1802 to 1852 was only 7 yards, and from 1852 to 1877 it was 10 yards. From here the clay cliffs gradually give place to the chalk, and the loss gradually decreases. Opposite the Methodist chapel at Sewerby village, the loss from 1802 to 1852 was only 9 yards, and from 1852 to 1877 only 5 yards. A little to the north of Sewerby Hall, the loss of ground from 1852 to 1877 amounted to 24 yards, doubtless due to a recent fall of the cliff.

From this point the cliffs present such resistance to the waves, that the loss is little more than nominal when compared with that of the cliffs already noticed. The decay that does take place here is principally due to the winter frosts.

2. An Account of the Engineering Works, &c. (Plate 4, Figs. 1–11.)

From what has already been stated under the head of loss at Hornsea, it appears that as early as the year 1609 the inhabitants were fully aware of the important part the old "pear" played in protecting the cliffs; not so much, the Author presumes, in the capacity of a breakwater as in that of a huge groyne causing a large accumulation of shingle beach.

According to Dr. Whewell's cotidal chart the tidal wave coming in from the Atlantic runs from the shore of the Firth of Forth to that near the Tees in one hour, and from the Tees to halfway between the Humber and the Wash, a distance of 105 miles, in two hours; so that the scour of this wave along the coast from Flambro' to the Spurn is very powerful, carrying with it in a southerly direction the shingle, sand, and mud from the cliffs, the beach travelling more slowly than the sand. It is upon this law that the most successful protective works are based; and it is evident that any diminution of the beach brings about a corresponding amount of actual damage, while any works which tend to increase the beach will most effectually oppose a resistance to the inroads of the sea.

For many years it had been the practice to remove the shingle for sale for the repairs of the parish roads. This custom grew to such an extent that it was not uncommon to see from twenty to thirty vessels beached between Withernsea and the Spurn, taking from 50 to 80 tons each, in a single tide. On the opening of the Hull

and Holderness railway the gravel trade received a great impetus. In 1868 the Board of Trade, by virtue of the Harbour Transfer Act of 1862, issued an order prohibiting the removal of shingle from any portion of the shore at Spurn for a distance of 2½ statute miles northward from the point. In 1869 the Board of Trade further prohibited the removal of shingle from any portion of the coast between Spurn and the northern boundary of Hornsea parish, and in 1869 and 1870 prosecuted certain persons for violating the law. In the evidence it was stated by Sir John Coode, M. Inst. C.E., in 1869, "that if the shingle continued to be removed the port of Hull would be endangered, and that materially so." Mr. James Oldham, M. Inst. C.E., stated that "the removal of shingle would result in the weakening of Spurn Point;" also, in 1870, that "every ton of shingle taken away resulted in damage to the coast." Capt. Cator, R.N., stated "that before the construction of Mr. Coode's groynes there were only 36 paces between high-water mark on the Humber side and high-water mark on the sea side. Now there is between 400 and 500 yards solid beach." "Taking the quantity at 25,000 tons per annum over a period of twenty years, from near Kilnsea, it represented a bank 3 miles long, 31 yards wide, and 6 feet deep removed." Mr. C. G. Clarke, of Withernsea, stated that from 200,000 tons to 250,000 tons had been removed along a length of 2 miles opposite Withernsea between the years 1854 and 1869, equal to 8,000 tons per mile per annum.[1] It is well worthy of remark that the waste of the cliffs prior to the gravel trade was only from 0·7 yard to 1·4 yard per annum. During the time when this trade was carried on the Author found that the loss had increased to from 3 yards to 6 yards per annum.

[1a] *Extract from Report of Capt. Vetch, Engineer to the Lords of the Admiralty, dated the 29th July*, 1850.

"I believe it may be safely assumed that during the last ten years it has not been less than 40,000 tons—but say 30,000 cube yards of solid material on the average per annum—and if this removal takes place along a length of 15 miles of shore, as alleged by one of the witnesses, there would still be an abstraction of 2,000 cube yards per mile per annum, which would amount to 11⅓ cube yards for every yard in length during the period of the last ten years, from which fact the full effect of the removal of stones may be truly appreciated; and from 1845 down to the present time the mischief which has occurred appears to have been but too truly anticipated both by the Tidal Harbours Commissioners and the Harbour Department of the Admiralty, and although, by direction of their Lordships, precautions were at last taken, they proved to be too late to avert the evil."

Spurn Groynes.

In 1864 six groynes were put down at Spurn Point by Sir John Coode, who has had the maintenance of the Spurn since 1863, with a view of collecting the shingle and increasing the beach on the sea side of the point. These groynes were placed at varying intervals from the extreme southern point to the north of the promontory. At the time of their erection the gravel trade had not been prohibited, yet they were so successful that subsequently other intermediate groynes were erected. In the discussion on Mr. Shelford's paper on the Humber,[1] Sir John Coode stated that his object in erecting them was essentially conservative, but the Author found by recent measurements that a great deal more than this had been accomplished. At the extreme point, and at a groyne a little to the north, the line of bent grass had extended 60 and 80 yards respectively to seaward beyond the original line, and along almost the entire neck this line of bents had travelled to seaward from 20 to 40 yards, covering a sandbank of drift from 6 to 10 feet high; which may be called a gain of land equal to 2 to 4 yards per annum. This accumulation of drift sand has been greatly accelerated by constructing small embankments of sand 6 to 8 feet high, and planting them on the top and sea face with bent grass, which binds the sand and prevents drift. During the last four or five years a plant has sprung up here among the bents called the sea buckthorn, which is of rapid growth and greatly to be recommended for similar situations. The Author estimates that there is an accumulation of bent-covered sand along the Spurn neck for a length of 2 miles, equal to 60 yards in width and 6 feet deep. Two groynes are laid down opposite the High Lighthouse, three opposite the site of the great beach of 1849, and others at different points along the entire neck. The first six that were erected are of Dantzig timber piles 10 inches square, shod with iron shoes and driven various depths into the beach. The planking is 3-inch red wood, secured to the piles by $\frac{3}{4}$-inch screw bolts and nuts. All butt-joints are made on and secured to the southern piles by $\frac{11}{16}$-inch wood screws and clip plates. The length of the groynes varies with circumstances, likewise the levels and rake of the pile-heads. When they were erected most of them stood five to seven planks above the sea beach at the land end. In September 1876 five of the groynes were covered with shingle to depths of 3 to 4 feet along most of their length.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 503.

The Author is of opinion that there is now an outer belt of beach, in addition to the high bent-covered sands, at least 100 yards wide, 7 feet in average thickness, and 2½ miles in length, equal to 1,250,000 tons of shingle, entirely due to the construction of the works of Sir John Coode, and the prohibition of the removal of shingle; and that the works have been a great success, and have rapidly reduced the chances of the sea outflanking Spurn Point. The cost of these groynes was about £6 per lineal yard.

Withernsea Groynes (Plate 4, Figs. 1–8).

In 1870–71 the Author, acting for Mr. C. G. Clarke, the contractor to the Withernsea Improvement Company (Limited), after obtaining a provisional order from the Board of Trade for the erecting of groynes and a promenade pier, now built, put down six groynes and an embankment across the low land from cliff to cliff. Two of these groynes were put down on the foreshore belonging to the North-Eastern Railway Company. Before their erection the beach was very low, and after a north-west gale, not uncommonly, the whole of it was swept away down to the bare clays. On the 8th of February, 1868, an unusually high tide occurred, doing alarming damage along the coast; the high-water mark of this tide (Fig. 1) reached a point about 400 feet to the landward of the present ordinary high-water mark. Groynes Nos. 1, 2, 3, 4, 5, and 6 (Fig. 1) were put down at intervals of 200 yards apart, at right angles to the beach, and varied from 300 to 350 feet in length. Figs. 2 and 3 are the section and plan of groyne No. 2; and Figs. 4 and 5 of groyne No. 4. The top of the groynes at the land end are 12 feet above ordinary high-water spring tides, the outer end being 3 to 4 feet above the beach. They were strutted at the south side to resist the pressure of the accumulating beach to the north; and, to oppose as little resistance to the breakers as possible, the top five rows of planks were only added as the beach accumulated.

The main piles are of Dantzig red wood, 13 inches square, 22 to 24 feet long, and shod with 14-lb. shoes of wrought-iron (Figs. 6, 7, and 8). These piles were driven 11 to 12 feet into the boulder clay below the sand. The strut piles are of red wood, 13 inches square and 12 feet long, driven 8 to 9 feet into the clay. The struts are of red wood, 13 inches wide by 6½ inches thick, dovetailed and halved on to the piles, and secured with 1¼-inch screw bolts and cast-iron washers. The planking is of red wood, 4 inches thick by 11 inches wide, in 20 to 25-feet lengths, secured

to the piles with 1-inch screw bolts passing through every plank and pile. Cast-iron washer plates were used in preference to wrought-iron, as the rust is less in the former than the latter. Every butt-joint, provided with a clip washer, was made on the north side of the south piles.

The breakers exerted the most destructive effect at a point corresponding with one and a half hours before and after high water; the temporary road for constructing the groynes for a length of 30 to 40 feet at this point being torn up, whilst above and below it remained unimpaired. Consequently, along this portion of the groynes, the Author caused 30-feet piles to be driven instead of the ordinary 22-feet piles. The result was that when these groynes were erected, most of them stood 8 to 10 feet above the high beach, and 4 to 6 feet above the outer beach; and when the Author took sections of the beach in June 1876, groynes 3, 4, 5, and 6 were entirely buried, and 1 and 2 were buried for two-thirds of their length. The ordinary high water spring tide mark is from 50 to 80 yards farther seaward now than formerly, and since 1871 there has been no loss of land along the coast thus treated. At less than $\frac{1}{4}$ mile to the southward of the last groyne, the sea at high water still reaches the cliffs, while to the northward the effect of the groynes is felt in keeping the high water from the foot of the cliffs for upwards of 1 mile.

The present beach varies in position with varying gales and seas; but the Author estimates that there is an average constant beach of 1,200 to 1,400 yards in length, by 100 yards broad, and 8 to 10 feet thick, or an accretion of 500,000 tons of shingle and sand, due to the prohibition of its removal by the Board of Trade and the effect of the groynes. In addition to the sea beach proper, there is a large accumulation of drift sand at the foot of the cliffs and the groynes, forming a high and dry beach, in many places covered with vegetable growth.

The cost of the groynes was £3 7*s.* 6*d.* per lineal yard. With the exception of No. 1, they have not suffered any material damage since 1871. The Author believes that they might have been placed 300 yards instead of 200 yards apart with equally good results, and at a considerably reduced cost per yard of protected sea frontage.

The effect of a south-east gale is to cliff out the beach 3 to 4 feet deep (Fig. 4), and to draw it down to what is called the outer beach; the shingle, however, soon returns to its original position. In January 1877 an extraordinary tide occurred, rising within 1 inch of the highest on record at Hull, and produced by a strong north-west gale which blew for some hours previously;

the tide caused serious damage to the coast generally. Although the sea rolled higher up the beach than on any previous occasion at Withernsea, no damage whatever was sustained by the protected cliff face or groyned frontage. The same tide caused a breach in Mr. Jackson's pile breastwork at Hornsea (described under head of "Hornsea Groynes") about 15 yards long, and some other minor slips.

Hornsea Groynes (Plate 4, Figs. 9–11).

On the foreshore of Hornsea, works comprising groynes and breastwork, &c., have been carried out by private enterprise. The Author has only noticed such as are most important. At the north end of this foreshore Mr. William M. Jackson erected two groynes in the year 1869, the northerly one being 132 feet long and the southerly one 102 feet long, at a distance of 150 yards apart. The piles are of Dantzig red wood, 12 inches square and 14 to 15 feet long, driven in pairs, each pair being 6 feet from centre to centre, with the space between filled with red wood planking, 3 inches thick by 11 inches wide. The land thus protected being composed almost entirely of gravel, Mr. Jackson erected a line of pile breastwork along the entire frontage, of which Fig. 9 represents a section of the south end. The breastwork was backed up with clay, and as it is protected by the groynes no loss has occurred since 1869-70. The cost of the groynes was £1 6*s.* 6*d.* per lineal foot, and that of the breastwork £4 per lineal yard.

At the north end of the breastwork a light revetment was constructed. Immediately south of these works are the Marine Hotel and its ruined grounds. When the protective works here adopted were carried out the cliff formed a small promontory of boulder clay about 25 to 30 feet high. The breastwork was about 110 yards long, and was adjusted to the form of the promontory. The piles were 13 inches square, driven 4 feet apart from centre to centre, with back waling 13 inches wide and 6½ inches thick, and planking 3 inches thick and 11 inches broad, all well bolted together, and tied with land-ties and piles. This work in December 1876 was in ruins, all the planks being gone except those buried below the sand, and many of the piles. At the north end (Fig. 10) the sea had encroached from 15 to 16 feet behind the piles; at the middle it had encroached 30 feet behind the piles; and at the south end the encroachments had been 62 feet. A groyne, run out from the most prominent point of this breastwork at a cost of about £3 10*s.* per lineal foot, was speedily destroyed.

At the southern limit of Hornsea foreshore Mr. Wade has erected

two groynes of a form new to this coast, being constructed of main and sheet piles. The main piles are 13 inches square, of Dantzig red wood 27 feet long, and are driven in pairs with two walings and a centre row of closely-driven sheet piles, 6 inches thick by 12 inches wide and 20 feet long; at the outer end the sheet piles are 3 inches thick by 11 inches wide, all bolted together. The Author believes that this form is not desirable, inasmuch as it presents too many interruptions on its face to the breakers, and also because the sheet piles being fixed at their ultimate height (about 9 or 10 feet) above the surface of the beach, present too great a resisting surface to the breakers, and are more exposed than that form of groyne which admits of the top planks being added and "built up" as the beach accumulates. The total cost of these groynes was about £600.

The Author's experience of the difficulty which exists in penetrating the wet sand beach down to the clay, in order to fix the bottom planks, leads him to believe that a combination of sheet piles at the bottom and of planks at the top is the most efficient form of groyne, both as regards strength and offering a minimum of useless resistance to the breakers. Fig. 11 is an elevation of this form of groyne, the main piles being driven zigzag with a waling between 6½ inches thick by 13 inches deep, fixed on the present level of the beach, sheet piles 6 inches thick by 12 inches wide driven into the clay on the north side of the waling and bolted to it. The top planking is gradually added as the beach accumulates, and is kept 3 to 4 feet above it. The cost of this form of groyne would be about £4 10*s*. per lineal yard.

3. The Effect of the Wasting Coast upon the Navigation of the Humber.

From what has been stated under the head of "Loss of Land, &c.," it is evident that the material of the wasting cliffs of Holderness ultimately finds its way to the Spurn Point, the lighter material and alluvium being carried into the estuary of the Humber, there to be deposited along its banks and bed. This seriously affects the navigation of the river, and is the cause of enormous expense in dredging at the Grimsby and Hull Docks. It appears to the Author that the chief cause of expense to these two flourishing ports, and the difficulties of the Humber Conservancy Commissioners, is to be found in a great measure outside the estuary rather than in the tributary rivers. Mr. Redman, M. Inst. C.E., in the discussion on the outfall of the Humber, estimates the amount

of material thus affecting the Humber at 3,000,000 tons per annum, taking the rate of degradation at 10 feet with a height of cliff of 30 to 40 feet.[1] The Author suggests that this does not adequately represent the actual amount of loss, since the clays below low-water level are eroded as well as the face of the cliff. At 1,000 yards from the shore there is a depth of 30 feet of water below low-water level, at which point, about four hundred years ago, there was a cliff 30 to 40 feet above high-water level; and as the range of the tide here is 18 feet, there is an actual loss at a point 1,000 yards from the shore equal to 90 to 100 feet in depth, the result of the falling of the cliff face and the subsequent abrasion of the submerged clays; this gives an average depth of 70 feet lost for every yard in width. Taking the coast at 40 miles long, and the average loss at a breadth of 2½ yards of land per annum, the amount of material travelling towards the Humber would be about 7,000,000 tons per annum. The Author believes that this plays a far greater part in the present condition of the Humber than the alluvium brought down by the land water of its tributary rivers.

It has been suggested that a pier near Kilnsea would be the best remedy for preventing this enormous amount of material from entering the Humber; but if this were constructed the Author is of opinion that the effect would only be partial; for whilst such a pier would stop the travel of the shingle, and cause it to accumulate for a time locally, its influence would not extend beyond 2 or 3 miles northward, and the great bulk of the coast towards the north would still go on wasting and keep up a constant supply of matter in suspension, and the travelling beach would ultimately round the end of the pier and find its way into the Humber. In the opinion of the Author a thorough system of groynes along the whole of this coast would be the most efficient method of protection, as the groynes would not only intercept the travelling shingle and prevent it finding its way into the Humber, but would effectually cut off the supply of alluvial matter, which is conveyed in suspension into the Humber, by protecting the cliffs from the ravages of the sea. Such a system, if commenced at or near the Spurn and proceeded with towards the north, by erecting groynes at intervals of 300 to 400 yards, would secure for the whole of this exposed coast a permanent and sufficient beach. If these groynes were each 300 to 400 feet in length, the cost would be approximately £1 10*s.* per lineal yard of protected coast; and, presuming that the whole of the cost fell upon the land (which

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 495.

the Author thinks should not be the case), it might fairly be apportioned by taking four parallel screeds of land along the entire coast, each measuring, say, ¼ mile in width, the first screed paying four-tenths, the second three-tenths, the third two-tenths, and the fourth one-tenth; this at 5 per cent. would amount to 7*s.* 4*d.* per acre for land in the first screed, 5*s.* 6*d.* per acre for land in the second, 3*s.* 8*d.* per acre in the third, and 1*s.* 10*d.* per acre for land in the fourth screed. Taking a length of 1,200 yards of coast, and the loss at 2½ yards per annum, there is an actual loss of land of from ¾ acre to 1 acre per annum, equal to £35 to £50 per annum. The interest alone on the cost of the protective works, as suggested, for the same length of frontage, would be equal to £90 to £100 per annum at 5 per cent., so that to the landowners as a whole it is cheaper to lose the land than to protect it. But the Author suggests that the owners of the land are by no means the only interested parties; and that beside the Humber Conservancy Commissioners, Trinity House, and the seaports of the Humber, it is a matter for the serious consideration of the Legislature itself.

This communication is accompanied by several maps and drawings, from which Plate 4 and the woodcuts have been compiled.

No. 1,551.—"Irrigation in the South of France: Department of the "Bouches-du-Rhône." By GEORGE WILSON, M. Inst. C.E.

THE department of the Bouches-du-Rhône is situated in the south of France, on the shores of the Mediterranean Sea. Marseilles is the chief town. The soil is mostly of a dry calcareous nature and the geographical position is such that generally but a small quantity of rain falls during the spring and summer months. Under the rays of a hot sun and a dry atmosphere, most of the crops become parched for want of moisture, and their production is consequently small in amount. But when the land is irrigated, under such a fine productive climate, crops of all kinds are both luxurious and abundant, consisting of wheat, rye, oats, barley, maize, grass meadows and pastures, luzerne, clover, potatoes, tobacco, madder, beetroot, hemp, vines, olives, mulberries, almonds, &c. Vegetables of all kinds. Fruits of great variety, such as peaches, pears, apples, apricots, plums, cherries, figs, quinces, medlars, pomegranates, jujubes, strawberries, melons, marjorams, mint, &c. The necessity for, and the great benefits to be derived from, irrigating the land have been known, appreciated, and practised by the inhabitants since the time that the Romans quitted the country, of whom there was an important colony in the Bouches-du-Rhône, the town of Arles was the centre of the colony.

The climate of the Bouches-du-Rhône, notwithstanding the mistral which blows occasionally, is considered one of the finest and most productive in France. There is comparatively little rain during some of the spring and summer months, and the temperature is high. The annual amount of rainfall varies considerably in different districts, and also yearly for each district, of the department. The following table (see next page) shows the average rainfall at Marseilles from 1860–1871.

This table shows that there is a mean rainfall of 11·2 inches for the seven months, March–September. The mean temperatures in the district of Marseilles, from observations continued during more than fifty years, are for the whole year, in degrees Fahrenheit 57°·9; summer, 70°·9 (the maximum being 92°·3 for nine years); and winter, 45°·5. In the district of Arles the mean temperatures for the whole year are 58°·8; summer, 74°·7 (the maximum being 99°·5), winter, 43°·5.

Seasons and Months.		Rainfall per Month.	Number of Rainy Days per Month.	Rainfall each Season.	Number of Rainy Days each Season.
		Inches.		Inches.	
Winter	December	1·5	5·2	4·9	15·4
	January	1·7	5·2		
	February	1·7	5·0		
Spring	March	2·1	6·6	5·2	15·1
	April	0·9	3·0		
	May	2·2	5·5		
Summer	June	1·1	3·5	3·2	8·8
	July	0·5	3·1		
	August	1·6	2·2		
Autumn	September	2·8	5·1	8·8	16·9
	October	3·3	6·1		
	November	2·7	5·7		
		22·1	56·2	22·1	56·2

For comparison with the above-mentioned rainfalls and temperatures in the Bouches-du-Rhône, the following are particulars of the same for Spain, Italy, and Algiers. For Spain, the mean temperatures at Madrid for summer, April–September, are 67°·8; winter, October–March, 48°·6; at Seville, summer, 81° Fahr., winter, 64°; at Valencia, summer, 75°·5; winter, 57°·6; at Alicante, summer, 71°·9, winter, 58°·8.

TABLE SHOWING ANNUAL RAINFALL in ITALY, ALGIERS, and SPAIN.[1]

		Inches.
Italy	Lombardy	38·0
	Piedmont	37·0
Algiers	Algiers	27·0
	Bôna	25·0
	Oran	14·5
Spain	Granada	33·42
	Seville	22·51
	Valladolid	20·86
	Zaragoza	17·03
	Valencia	15·88
	Alicante	13·58
	Madrid	11·98

[1] "Irrigation in Spain," by George Higgin, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. xxvii., p. 483.

TABLE SHOWING COMPARATIVE MEAN and MAXIMUM TEMPERATURE and MEAN RAINFALL of ITALY and SPAIN DURING the SEVEN IRRIGATING MONTHS from MARCH to SEPTEMBER.

		Mean Rainfall.	Mean Temperature.	Maximum Temperature.
		Inches.	Fahr.	Fahr.
Piedmont	General average . .	29·00	63°·2	85°·3
Lombardy	Milan	22·00	63·2	85·9
	Pavia	22·00	66·1	88·0
	Brescia	22·00	65·3	86·4
Spain	Madrid	5·31	64·7	98·0
	Alicante	7·66	69·4	94·0
	Valladolid	8·98	62·5	90·0
	Seville	5·45	78·0	111·0

The system of irrigation has been for centuries gradually extended in the department of the Bouches-du-Rhône, necessitating the execution of important canals and works, some of which are not surpassed in an engineering sense by any others for a similar purpose, resulting in enormously improving and enriching the country. The geographical position of a large extent of the department is admirably situated for the purpose of irrigation by means of the water of the river Durance, which flows along the north side of the department at a considerable altitude.

In Plate 5 is shown a map of a portion of the department with the main irrigating canals, &c., the particulars of which are stated in the reference on the map.

Before describing the mode and results of irrigation in the Bouches-du-Rhône, a brief description will be given of the river Durance, from which the irrigation canals mostly derive their waters, and also a few details of four of the main irrigating canals.

THE DURANCE.

The source of this river is in the Alps, separating France from Italy, and the river flows into the Rhône near Avignon. Its mountainous basin is about 5,200 square miles superficial area, and its main tributaries are the rivers Verdon, Asse, Bléone, Ubaye, and the Guil, all of which are generally torrential. The inclination of the bed of the Durance is considerable; it increases

continually in steepness in following its course from its conflux with the river Rhône up to its mountainous basin in the Alps. From the river Rhône to Mallemort the inclination is about 1 in 500, from that point to Pertuis 1 in 400, then 1 in 330 to the junction of the river Verdon, and 1 in 250 to the junction of the river Bléone, after which the inclination becomes excessive up to the source of the river. The quantity of water in the Durance, at extreme low water and at the greatest floods, varies from about 1,400 to 210,000 cubic feet per second. At ordinary low water there is a flow of about 2,540 cubic feet per second. A large quantity of sediment is carried in the water of the Durance, estimated at about 17,000,000 tons per annum. This sediment being a rich alluvial soil, containing more than 40 per cent. of carbonate of lime, flows into the river Rhône, and is deposited by that river, near its mouth, in the Mediterranean Sea. The immense Carmargue plain, near the mouths of the river Rhône, embracing an area of more than 220,000 acres, has been gradually formed, in the course of time, by means of the alluvial deposits of that river, and the process is still going on, gradually extending the plain further into the sea. At a remote chronological period the town of Arles was close to the sea; whereas, at the present time, the sea is 24 miles distance from that town. A more recent estimation of the extent of this alluvial deposit is afforded by the fact that the tower of St. Louis was built in 1737, near one of the mouths of the river Rhône, and that at the present time the sea is about $3\frac{3}{4}$ miles distant from that tower.

In addition to the sediment mechanically suspended, the Durance waters hold much valuable agricultural matter in solution, which is considered the main cause of the waters of that river being so valuable for irrigating purposes. The quantity of sediment mechanically suspended increases with the flow of the river. The ordinary maximum is about 30 grammes of sediment to 1 litre of water, equal to a proportion of $\frac{1}{33}$ by weight. In exceptional cases, as in August 1858, the proportion was as high as 100 grammes per litre of water, or $\frac{1}{10}$ by weight. In extreme low water the proportion by weight is about $\frac{1}{10000}$. The average proportion for the nine years 1867–75 was about $\frac{1}{550}$. For irrigating purposes the water, when containing much sediment in suspension, is injurious if caused to flow over certain crops, excepting in such cases where it can be applied only to the roots. The following analysis by M. Paul de Gasparin, of the Central Society of Agriculture of France, shows an average composition of the matter held in solution in the water of the Durance after being filtered.

The proportion of solid matter being about $\frac{1}{1600}$ the weight of the water.

	Per cent.
Silicic acid	1·28
Phosphoric acid	0·04
Sulphuric acid	12·67
Chlorhydric acid	4·35
Carbonic acid	41·70
Lime	31·56
Magnesia	2·74
Soda	3·84
Potash	1·82
	100·00

For comparison with the above, the following is an analysis, by Dr. Voelcker, of the proportion of the solid matter held in solution in the clear filtered water taken from the river Nile at the beginning of the rise. The proportion of solid matter, when dried, held in solution being about $\frac{1}{4000}$ of the weight of the water:—

	Per cent.
Oxides of iron and alumina with traces of phosphoric acid	0·38
Silicate of lime	10·00
Carbonate of lime	23·54
Carbonate of magnesia	15·15
Carbonate of potash	3·56
Carbonate of soda	17·56
Chloride of sodium	12·40
Sulphate of potash	5·02
Nitrate of potash	0·97
Organic matter	11·42
	100·00

A quantity of the sediment, mechanically suspended, taken from the river Durance, was submitted to Dr. Voelcker for analysis, and gave the following result:—

	Per cent.
Organic matter and water of combination [1]	2·770
Oxide of iron	4·348
Alumina	1·550
Phosphoric acid	0·102
Carbonate of lime	42·625
Sulphate of lime	1·197
Magnesia	1·250
Potash	0·434
Soda	0·222
Nitric acid	0·001
Insoluble siliceous matter	45·501
	100·000

[1] Containing nitrogen . . . . . 0·063 per cent.
Equal to ammonia . . . . . 0·076 „

For a distance of about 60 miles, between the points of conflux of the rivers Verdon and Rhône, the Durance flows at an altitude of several hundred feet above the level of the sea. There is thus ample fall for its waters to flow along the numerous canals on to the land by gravitation.

The Crapponne Canal.

The authority to construct this canal was conceded to Adam de Crapponne, an eminent engineer, in the year 1554. It takes its water, through sluices, from the river Durance, near to St. Estève-Janson, at an altitude of 492 feet above sea level. There the river varies from 600 to 6,500 feet in width, and the bed consists of a succession of sand and gravel banks, and alluvial deposits, intersected by numerous branches, which shift at every flood. Such a state of things cannot be considered as constituting the bed of a river, in the ordinary acceptation of the term, and to have constructed a permanent and fixed barrage across the river, to lead the water through the sluices, would have been not only a costly work at that remote time, but also one of considerable difficulty. Crapponne constructed, therefore, what are termed *barrages volants* across the river. These are formed, where the depth of water is about 2 feet, by stakes with fascines, and filled in with stones. In the deeper parts of the river, which may be sometimes 12 to 15 feet, *chevalets* in place of stakes are driven, consisting generally of trunks of trees cut near the point of the bifurcation of the principal branches, and which are placed closer together in proportion to the depth. The chevalets are bound by cross-pieces and supported by fascines. These barrages volants are always placed obliquely to the current of the river, for the purpose of causing the fascines to press against the stones or the chevalets. Such barrages volants need continual repair, but their cost is comparatively trifling. It is mostly a question of labour, as the material employed is cheap. The average cost of maintenance of the barrage for the Crapponne canal is about £500 per annum. This system, adopted by Crapponne more than three hundred years ago, has never been changed, and has been found by experience to answer its purpose of diverting the Durance waters through the sluices into the canal in all seasons; and the same system is adopted for some other irrigation canals. The Crapponne canal, being the main canal from the river Durance, to Lamanon, is 14¼ miles in length. At Lamanon the canal has two main branches, one flowing south towards Salon and St. Chamas, and the other to the west towards Arles. The total length of the

canal, with its branches, is about 77 miles, not comprising the whole development of the branch to Arles, which is a special property independent of the original canal. The quantity of water supplied by the canal is as follows:—The main canal is 26 feet wide, and 6·5 feet deep; the mean velocity is 5 feet per second. The branch to Salon is 10 feet wide, and 6·5 feet deep; the mean velocity is 6·5 feet per second. The branch to Arles is 16·5 feet wide and 3·28 feet deep; the mean velocity is 5·3 feet per second. The branch to Istres is 6·6 feet wide, and 3·3 feet deep; the mean velocity is 6·6 feet per second.

Crapponne ruined himself in carrying out the works, and in order to raise funds and satisfy his creditors, he was compelled to grant concessions for the use of the water at very low prices. These concessions have given cause to continual law-suits and troubles in the administration of the canal, and have been a hindrance to the proper development of the canals. The volume of water employed is from 350 to 500 cubic feet per second for irrigating purposes, and for moving thirty-three mills situated on the course of the canal. But the canals are of sufficient capacity for a volume of 850 cubic feet of water per second, and it is estimated that the area of the land upon which the waters of the Crapponne canal could be caused to flow for irrigation is more than 100,000 acres. The surface actually irrigated by the canals, including the branch to Arles, is about 24,000 acres.

The Alpines Canal.

This, which was commenced in 1773, takes its water, for the main channel, from the Durance at Mallemort, and for the west branches near Châteaurenard. The main canal is considered one of the best in Europe as regards its utility. The system consists of more than 194 miles of canal, disposing of 770 cubic feet of water per second, which with the west branches of the canal, irrigates more than 20,000 acres. The branches to Tarascon and Barbentane have generally an inclination of 1 in 2,000. In some portions of the former branch the inclination is 1 in 4,500; in other portions 1 in 1,250; while over some of the aqueducts it is as much as 1 in 154. The widths at the bottom of the west branch canal vary from 7·8 to 9·2 feet, and for the branch to Barbentane between 5·2 and 6·2 feet. The inclination of the slopes varies from 1 to 1 to 1½ to 1 in ordinary cuttings and embankments. The west branches of the canal have passed through considerable financial difficulties, and are now managed by an independent company.

In order to develop irrigation, numerous syndicates have been formed, as some of the land was held in small parcels by proprietors and farmers who had neither the funds nor the power, in opposition to intervening landowners, to obtain branches to conduct the water from the main irrigating canal to their properties. The price charged for the water is regulated by the price of corn, on the basis of 1·66 bushel per acre irrigated. The quantity of water given at the above rate is fixed at about 0·57 gallon per acre per second, supposed to flow continuously during the irrigation season, commencing on the 1st of April, and terminating on the 1st of October of each year, which is equal to covering the ground for the total number of irrigations to a depth of 66½ inches, and with 22,130 cubic yards of water. In 1874 the cost of irrigation was equivalent to about 11*s.* 6*d.* per acre, being the price of 1·66 bushel of corn. The price has recently been reduced to about 8*s.* per acre, for three irrigations required during the season for such crops as corn and olive orchards. The same reduced price per acre is also charged for inundating vineyards during the autumn, as a preventive to the phylloxera.

The Marseilles Canal.

This canal, one of the most important engineering works in France, commenced in 1837 and completed in 1848, is constructed for the double purpose of supplying the town of Marseilles with water and for irrigation. The canal takes its water from the Durance, near the suspension bridge at Pertuis, at an altitude of 614 feet above sea level. The greater portion of the main canal is constructed through a hilly country. It is 51½ miles in length to the boundary of the Marseilles territory, 10 miles of which is through tunnels. Three of the principal tunnels are each about 2·18 miles long. The canal, on arriving in the territory of Marseilles, continues for a distance of 26¼ miles to Montredon. There are, in addition, five branches of a total length of 21¼ miles. The main canal is 9·84 feet wide at the bottom, 30·8 feet wide at the top, and 7·87 feet deep. The inclination of the canal is 1 in 3,333. Its maximum capacity 424 cubic feet of water per second. One of the numerous important works of art on this canal is the Roquefavour aqueduct,[1] 1,253 feet in length, 271 feet in height above the river Arc, and constructed with three tiers of arches.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 190.

The following are the principal dimensions of this aqueduct:—

	Feet.
Length	1,253
Total height above low water of the river Arc	271
Width of the piers at the base	44½
„ „ „ top	14¾
Number of arches in first tier, 12.	
„ „ second tier, 15.	
„ „ third tier, 53.	
Span of arches in first tier	49¾
„ „ second tier	52½
„ „ third tier	16½
Width of the water-way of the aqueduct	7½
Depth „ „ „	7⅞
Inclination of the water-way, 1 in 250.	

Other important works consist of the dam across, and inlet sluices at, the river Durance; and settling basins, to rid the water of the sediment mechanically suspended, in order to render the water fit for domestic purposes. Four such basins have already been silted up with the sediment deposited in them, and the fifth, the Réaltort basin, 173 acres in superficial area, and having a capacity of about 159,000,000 cubic feet, is also fast filling up. In consequence of the continual silting up of the settling basins, another basin, with the necessary works for flushing it out, estimated to cost £65,000, is being executed in the valley of St. Christophe, situated near the Durance, 9¼ miles below the sluice through which the canal takes its water from the river. It is formed by constructing a masonry dam across the valley, 218 yards in length, 72 feet in height, and 55¾ feet in width at the base. The superficial area of the basin will be 57 acres, and its capacity equal to 81,000,000 cubic feet. At the end of each year, when a depth of about 5 feet of sediment has accumulated at the bottom, it will be flushed out into the river Durance at a lower level. The total cost of the canal to 1876 has been £1,792,800, which includes land, works, settling basins, and laying the pipes for supplying the town of Marseilles with water. To cover the above cost, and for payment of interest, the town of Marseilles has borrowed from time to time £2,279,000, which sum is to be redeemed partly by the revenues derivable from the canal, and partly by specified taxes; particularly by an additional tax on flour, which produced a sum of £41,160 in the year 1875. More than two thousand occupiers of land subscribe for the water for irrigation, and the total area under irrigation is more than 8,000 acres. The owners of one hundred and seven mills use the fall of the water in the canal for motive-power, developing 1,592 HP.

The revenue derived from the Marseilles canal for 1876 has been :—

	£.
Town subscription	13,400
Country „	25,000
Subscription for motive power	16,320
Payments by new subscribers for connecting works .	4,600
Total	59,320

The annual cost of maintenance of the canal is important.

The Marseilles canal, belonging exclusively to the town, has not been subjected to financial difficulties. Some of the other irrigation canals, however, in the Bouches-du-Rhône have had to make from time to time disastrous concessions to raise funds; thus causing not only obstacles in developing the resources of the water to the best advantage, but also a reduction in the anticipated revenue, so much so as to give no encouragement to the shareholders.

The tariff arrangements and regulations of the Marseilles canal for the distribution of the water, as determined by the municipal council and fixed by the Prefect of the Bouches-du-Rhône, for irrigation and water-power, are as follows; subscriptions for the water being limited to a duration of fifty years.

Water supplied periodically, or for irrigation, including the expense of the connecting conducts and annual payment—

Quantity of Water supplied per Second for a period of Six Months.		Amounts to be Paid for making connecting Conducts.	Annual Subscriptions.
In Litres.	In Cubic Feet.		
		£.	£. s. d.
1·00	0·0353	16	3 4 0
0·50	0·0176	8	1 16 9

Not less than half a litre (0·44 quart) per second can be subscribed for.

Water supplied continuously in the district—

Quantity of Water.			Amounts to be Paid for making connecting Conducts.	Annual Subscription.
In Modules.	In Litres per Twenty-four Hours.	In Cubic Feet per Twenty-four Hours.		
			£. s.	£. s. d.
2·00	17,280	610·17	20 0	7 12 0
1·00	8,640	305·08	10 0	4 12 0
0·50	4,320	152·54	5 0	2 17 7
0·20	1,728	61·02	2 12	1 15 2
0·10	864	30·51	1 8	1 1 7

The water measuring $\frac{1}{8}$ module is only supplied in the country for lands less than 20 ares area (0·494 acre), and $\frac{1}{10}$ module when the area is 10 ares and under.

The tariff for the use of the water for motive-power at the numerous falls along the canal is £11 per horse-power per annum, but it must be subscribed for a period not less than six years. A horse-power is fixed at 100 litres of water falling 1 mètre per second, equal to 43,296 lbs. falling through 1 foot per minute. The water, after being used for motive-power, must be returned to the company's canal at a lower level, and not appropriated for any other purpose except by special arrangement with the town. When the water is not used by subscribers for irrigation, it can be employed temporarily for motive-power at the rate of £1 per HP. per month. In addition to the above charges, the subscribers have to pay for the cocks, or sluices and overflows for the purpose of obtaining and regulating the quantity of water subscribed for. The town undertakes to execute these works, payable in advance, for a fixed amount of 12*s*. per conduct for water taken periodically, and £1 4*s*. for water taken continuously, comprising the regulator, &c. It delivers the water by a conduit, whether open or covered, up to the boundary of each property, maintains the conduits, and does the service for regulation. The above are the general charges for water; but in some special cases, where additional canals have been made and the ground is more difficult, the prices to subscribers are increased both for the first outlay and for the annual cost of the water. The season for irrigation is fixed for a period of six months, commencing on the 1st of April, and terminating on the 1st of October. The quantity of water, subscribed for by each proprietor, means that the subscriber is entitled to receive the quantity agreed upon per second supposed to flow continuously for six months, the season for irrigation. For example, suppose a proprietor subscribes for 1 litre per second, he would be entitled to receive, at fixed periods, as many litres of water as there are seconds in six months. The town sends to each subscriber, before the 1st of April of each year, a table showing the dates and hours at each date that the water will be supplied to him during the season. It is found from experience that 1 litre of water per second is a good average quantity to irrigate 1 hectare, or 2·47 acres, of land. One litre of water per second (supposed to flow continuously) for six months, say one hundred and eighty-three days, is equal to 15,811,200 litres, which is sufficient to cover a hectare of ground with water to a depth of 62½ inches. That volume of water may be used during the season by forty-three irrigations, each of three hours duration,

with a flow of 34 litres per second. The ground, in such a case, would be covered at each irrigation with water to a depth equal to a fraction less than 1½ inch.

The water of the Marseilles canal, to the end of 1876, was disposed of as follows:—

——	Litres.	Cubic Feet.
	Per second.	Per second.
For irrigation, already subscribed for	3,530	124·61
Continuous water, subscribed for in the territory .	512	18·07
For Canal d'Aubagne	1,000	35·30
For watering roads.	250	8·83
For fountains	100	3·53
For the streams des Ayglades, Jarret, &c. . . .	560	19·77
For public service, supply of the town of Marseilles and purifying the port	2,400	84·72
Losses by percolation, evaporation, and at the settling basins	1,648	58·17
	10,000	353·00

The maximum quantity of water which the concession determines may be drawn from the river Durance is 9,000 litres, or 318 cubic feet per second, comprising 1,000 litres for the Canal d'Aubagne. The available water is therefore fully used. To irrigate an increased area of land the town of Marseilles can only supply the water by taking measures to decrease the losses by percolation and at the settling basins, estimated, including losses by evaporation, at 1,648 litres or 58 cubic feet per second; and in purchasing some of the smaller independent canals to which water is conceded from the Durance and only partly used for irrigating or other purposes.

The Verdon Canal.

This canal was commenced in 1863, and opened at the end of 1875, for supplying water to the town of Aix, for irrigating purposes, and for motive-power. It takes water, at Quinson, from the river Verdon, a tributary of the river Durance. An important overflow barrage had to be constructed across the river Verdon, 36 feet 1 inch high and 138 feet long, to raise the water to the sluices. The cost of the barrage and intake at the river was £35,770. The main canal is 51¼ miles in length. The inclination is at the rate of 1 in 4,000 to 1 in 5,000, except through the tunnels, where it is 1 in 909. The canal has a sectional area of 113 square feet. Through the tunnels the sectional area is

52½ square feet. The number of tunnels is seventy-nine of a total length of 12½ miles, the three most important of which are respectively about 3¼, 2⅝, and 1⅞ miles long. There are numerous aqueducts, bridges, and culverts, and the difficulty of the ground has necessitated constructing the canal by retaining walls for a length of nearly 4 miles. There are, in addition, several syphons; four of which are across deep valleys. The most important is that at St. Paul, 890 feet long, constructed of two parallel wrought-iron tubes, each 5 feet 9 inches in internal diameter, with a maximum pressure equal to 116⅜ feet head of water. The horizontal portion of the syphon, laid at the bottom of the valley, is 321·64 feet in length. The remainder of the length of the syphon, consisting of the two inclines, is laid at a slope of about 2½ to 1. The pipes are of wrought iron, and respectively 0·353 inch and 0·315 inch thick for the horizontal and inclined portions. They are supported on, and fixed in, masonry at the junctions of the horizontal and inclined portions. The remainder of the lengths bear on cast-iron rollers resting on stone blocks, placed about 31 feet apart. The arrangements for expansion and contraction consist in constructing a short length of the tubes, in each of the horizontal and inclined portions, of a gradually increasing diameter from, and then decreasing back to, the normal diameter of the tube. The metal of the tubes at these swellings is reduced to about ¼ inch in thickness, in order to obtain greater elasticity, and it is contended that the bulging in and drawing out of the tube, at these swellings, will respectively allow for expansion and contraction of the metal.

The following is the cost of the canal:—

	£.
Land	27,972
Earthworks	81,182
Tunnels	169,024
Aqueducts and syphons	39,223
Dam and sluice	35,770
Retaining walls, pitching, revetments, puddling, &c.	49,506
Irrigating canals	15,900
Ordinary works	23,894
Plant, pumping, &c.	9,009
Staff expenses, &c.	39,152
Administration, printing, &c.	5,738
Interest at 6 per cent. on loans and sundries	155,322
	£651,692

In addition to this cost, more than £200,000 will have to be

expended, mainly for branches of the canal, to complete the work.

At the commencement the long syphons on this canal, including that of St. Paul above described, were constructed through the natural rock, and lined with masonry to prevent leakage, at a depth of 50 to 82 feet below the bottom of the valleys. The rock being intended to resist the hydraulic pressure. [After completion, not one of these tunnel syphons acted satisfactorily when the water was let into them. Repairs were then commenced, experimenting at first with those under the least, and ending with those under the greatest head of pressure. After much trouble and expense all were at length caused to act satisfactorily, with the exception of that of St. Paul, which had to be abandoned.

The canal has eight branches, of a total length of about 47 miles, which, similar to the main canal, have necessitated the construction of numerous works of art, comprising an aqueduct 3,625 feet long, and 27 feet in maximum height; a syphon 443 feet long, under a head of pressure equal to 71½ feet, and a tunnel 1,038 feet long.

The capacity of the main canal is equal to the supplying of 212 cubic feet of water per second, the quantity conceded; and there exists, at the numerous falls along the canal, water-power to the extent of 2,000 HP., which is fixed to be let at £8 per HP. per annum. The extent of land which can be irrigated by the canal, is about 40,000 acres; but, after deducting the water required for domestic and other purposes, the capacity of the canal is only sufficient to irrigate a portion of that area. The price charged for the water for irrigation is at the rate of 22*s.* 9*d.* per acre per annum for the commune of Aix, and 20*s.* for other communes. In the former case the company pay the cost of the conduit to the land; while in the latter such cost is paid by the irrigator. The quantity of water supplied at those prices is fixed, as is customary in that part of the country, at 1 litre per second, supposed to flow continuously from the 1st of April to the 30th of September, sufficient to irrigate 2·47 acres of average land. Soil of a light porous nature also for certain crops requiring more, and heavy soil and other crops less, than that quantity.

In addition to the four principal canals above described, there are numerous others in the department of the Bouches-du-Rhône. The total length of the whole of the canals exceeds 600 miles, with a capacity of about 2,000 cubic feet of water per second. The following is an an approximate statement of the whole of the irri-

gating canals, and the area of land irrigated in the Bouches-du-Rhône.

Name of the Irrigation Canals.	Surface Irrigated.
	Acres.
Crapponne, general	16,920
„ branch to Arles	6,357
Alpines	16,333
„ West branches (French company)	4,337
Marseilles	8,644
Aubagne	1,038
Peyrolles	1,112
Peyrolles Mill	618
Puy-Sainte Réparade	618
Châteaurenard	6,422
Réal de Châteaurenard and Eyragues	1,482
Derivation of the Huveaune	1,514
Gemenos and other minor canals in the arrondissement of Marseilles	413
Canals in valley of the Arc	1,245
Canals of the Touloubre	218
Other minor canals in the arrondissement of Aix	727
Other canals in the arrondissement of Arles, in addition to those above designated	5,587
Irrigation with water taken from the river Rhône	13,090
	86,675
These irrigations are effected with water derived as follows :—	
Irrigations from the river Durance	66,394
„ from the rivers Huveaune, the Arc, the Touloubre, and minor streams	7,191
„ from the river Rhône	13,090
	86,675

The other departments of France, where irrigation is the most extended, are the Vosges, where the amount is 140,000 acres; the Arriége, 93,000 acres; the Haute-Saône, 45,000 acres, and the Hautes-Alpes 35,000 acres.

System of Irrigation.

The water flows through a sluice from the main irrigating canal along a small canal or conduit to the limit of the property to be irrigated. The land is divided into compartments, the dimensions of which are regulated according to the nature of the soil, whether light or heavy, flat or hilly land, and also the crops to be grown. The circulating canals are generally 2 feet wide at the bottom, 2 feet 2 inches deep, with slopes from 1 to 1, to 1½ to 1. They are laid out so that the water is about 1 foot above the land

to be irrigated, and can be caused to flow freely into each compartment of the land under irrigation. When the circulating canals do not form one entire compartment to be irrigated, as may be the case when the land is flat, small banks or mounds are made for inclosure, which are generally 1 foot to 1 foot 6 inches high, and 1 foot 6 inches wide at the top. On flat land, which is not too porous, and for certain crops, the water sometimes flows over the land for a distance of 240 yards; but this may be considered the maximum distance under the most favourable circumstances. In most cases the distance is much less. On sidelong ground, if the inclination be considerable, the compartments are narrow; and generally the inclination is lessened by transporting a portion of the soil from the higher to the lower side of a compartment. But ground having a considerable slope, as much as 2 to 1 in very exceptional cases, is irrigated where water is abundant. The ground is reduced to an inclination of about 1 in 500 where possible, and the expense not too great.

The small sluices, built in the circulating canals in order to turn the water into the compartments, are simple and cheap. The arrangement comprise, for the most part, two blocks of stone forming the sides resting on another block of stone for a cill laid across the bottom of the canal. The sluice consists of a thin plate of wrought-iron, having a handle at the top, which is lifted in and out of two grooves cut in the side blocks of stone as may be required to open or close the sluice. These small sluices have openings, for the main circulating canals, from 14 to 18 inches, and those for minor canals 8 to 10 inches wide. The overflow dams are constructed in a similar manner to the sluices, with stone blocks for the side, resting on a stone cill. The most approved plans of the circulating canals, mounds for dividing the ground into compartments, small sluices, and overflow dams, is shown in Plate 6.

Plate 6 also shows an example of a property, consisting of meadows, the ground being hilly, as actually laid out for irrigation, the particulars of which are given in the reference. The cost of the large sluices is about 30*s*., of the smaller, 12*s*., and of the overflow dams 7*s*. each. The cost of laying out the land complete for irrigation, which necessarily varies greatly according to the nature of the soil, the crops to be grown, and the contour of the ground, is from £8 to £30 per acre. The time for irrigation commences on the 1st of April, and terminates on the 30th of September. The standard quantity of water adopted in the country is 1 litre of water, supposed to flow continuously for six months, per hectare.

This quantity of water would cover the ground to a depth of about 62¼ inches; consequently gives fourteen irrigations, each of about 4½ inches; twenty irrigations of about 3 inches, or forty-three irrigations of about 1½ inch depth of water.

The quantity of water used during the season for irrigation in Lombardy is about 1 litre per second per hectare, the same as in the Bouches-du-Rhône; while in Spain and India, countries where a greater quantity might be considered necessary, it is estimated that the amount used is only about ½ litre per second during the season, and that quantity is thought an ample dotation. These great differences are doubtless owing partly to the nature of the crops irrigated, and partly to the degree of perfection of cultivation in the respective countries.

There is no fixed rule in the Bouches-du-Rhône as to the number of irrigations for such crops which require periodically irrigating during the whole season, as this must necessarily depend to a great extent upon the nature of the land, whether light or heavy, whether flat or sloping. In most cases the water is given by the companies once a week, which would be equal to twenty-six irrigations during the season. The Marseilles canal gives the water forty-three times during the season. Grass lands and gardens are usually irrigated at intervals of eight days; also madder-root, potatoes, and beans; but these latter do not require irrigating periodically during the whole extent of the season. Lucerne is generally irrigated at intervals of twelve days to a depth of about 2½ inches of water; wheat, oats, and barley are irrigated once, twice, or thrice, each season according to the dryness of the weather, in April or the beginning of May. The depth of water is about 2½ inches for each irrigation. Olive orchards are irrigated twice a year, in June and August, to a depth of about 2 inches each irrigation. Vines are not systematically irrigated, but sometimes, when the season is very dry, one or two irrigations are given where facilities exist for the operations. Grass, lucerne, beans, and most vegetables are cultivated on the natural flat ground, provided the water is sufficiently clear, which does not injure such crops by wetting them just above the ground. But if the water be muddy it is very injurious to all the crops. The mud in the water if deposited at and around the roots of the plants, hinders their growth, and sometimes destroys them. To lessen the effects of muddy water, on some properties, settling reservoirs are made for the water to flow into before entering the irrigating channels. In case of muddy water, suitable trenches are ploughed or dug out in the ground; in these the irrigating water is caused to flow and per-

colate through the soil to the roots of the crops. Some crops cannot be irrigated without injury, except the roots; such, for example, as potatoes.

The benefits derived from irrigation in the Bouches-du-Rhône, although not so great as in some parts of Spain in comparison with non-irrigated lands, are nevertheless considerable. In Spain there is less rain, and in most districts a hotter climate, consequently the effects of irrigation are more marked. But in the Bouches-du-Rhône there is, nevertheless, comparatively a small quantity of rain during the spring and summer months, the climate is fine and hot, and the soil is mostly of a calcareous nature. Grass meadows, when irrigated, are cropped three to four times each season; the produce is from 3½ to 5¼ tons of hay per acre. Potatoes, when irrigated, produce from 14 to 25 tons per acre. Wheat and oats, when irrigated, yield an increased produce of about 30 to 50 per cent. in comparison with crops not irrigated. Lucerne when irrigated is cut six times, the produce being from 3½ to 6½ tons of hay per acre.

The following example shows the average produce and cost of cultivating an acre of lucerne on good land:—

Crop.	£. s. d.	£. s. d.
1st cut 735 lbs. of hay per acre		
2nd „ 1,548 „ „ „		
3rd „ 2,627 „ „ „		
4th „ 2,517 „ „ „		
5th „ 1,848 „ „ „		
6th „ 580 „ „ „		
9,855 = 4·4 tons at £4	..	17 12 0
Grazing land during winter	..	0 8 0
		18 0 0
Cost per Acre.		
Irrigation	0 17 6	
Mowing, &c.	0 16 3	
Transporting, &c.	0 4 9	
268 lbs of guano (or other manure)	1 16 0	
Spreading „	0 1 0	
		3 16 0
Profit per acre, not including rental	..	£14 4·0

An example of the produce of irrigated grass meadows on good land is similar in the result to that of the lucerne just mentioned. The hay was sold for £17 16*s.*, and £1 realised for winter sheep-grazing per acre. The expenses, including the cost of manure, amounted to £4 16*s.*, thus showing a net profit of £14 per acre. Meadows under irrigation are soon exhausted unless annually well manured. This is done at the rate of 8 tons per acre per

annum on good land; in some cases guano is used in alternate years in place of ordinary manure. The net revenue of good land under irrigation, all expenses paid, varies from £3 to £14 and more per acre according to the situation of the land and the nature of the crops grown. This is from 30 to 50 per cent. for cereals, increasing to 400 per cent. and more for other crops, a greater net revenue than is obtained from cultivating the same land not irrigated. The net profits realised in irrigating cereals being less marked than for some other produce, the outlay for preparing cereal ground for irrigation has hitherto been sparingly given, but now the irrigation of cereals is increasing.

In numerous cases of farms under irrigation, the proprietor, instead of a fixed rent, takes one-third or half the gross annual revenue. The farmer supplies the manure, and pays all expenses excepting the annual rate for irrigation water, which is generally paid by the proprietor. The net annual profit to the proprietor under this arrangement, on good meadow land, is £6 10*s.* per acre. The above figures mainly refer to good land under irrigation, but the results of irrigation on poor land are comparatively even more important. The Crau plain consists of land upon which scarcely anything grows; the surface is clay soil, about 9 inches in thickness, covered with small boulders and stones. Under the surface soil is a hard compact layer resembling béton, termed in the country "Poudingue." The plain has a uniform inclination of about 1 in 300. In spring and summer the comparatively small quantity of rain which falls on the plain flows down it, and is rapidly evaporated by a hot sun, there not being sufficient time for the clay soil to absorb the rain. The result is that the surface of the plain is sometimes almost as hard as baked brick. The value of this barren plain, in its present condition, is about £2 per acre; but those portions of it now under irrigation are enormously increased in value thereby. The following example shows the results of irrigating the barren land:—

COST PER ACRE IN PUTTING THE LAND UNDER IRRIGATION AND ESTABLISHING MEADOWS.

	£.	s.
Gathering stones off the surface	1	13
Ploughings, harrowings, &c.	1	17
Levelling, and irrigation drains	2	10
Lucerne seed	1	6
Manure (about 16 tons the first year)	8	0
Spreading manure and sowing	1	2
Purchase of land	2	0
	£18	8

The annual produce per acre is 3¼ tons of hay, which at £4 per ton produces £13, in addition to 15*s.* for grazing during the autumn and winter. Supposing the total annual expenses to be £6, including cost of a sufficient quantity of manure and irrigation water-rate, the net profit would be £7 15*s.* per acre on this formerly barren land. To maintain the crops at their annual maximum, about 50 per cent. more manure is required for land of inferior quality. It is customary in the Bouches-du-Rhône to sow lucerne in the first instance. In the course of time, after regularly irrigating, the herbs gradually change, and ordinary grass meadows are established.

The price of good land for general cultivation is doubled in value by irrigation. For meadows and some other crops it is increased threefold. In Spain it is estimated that the value of good land in the valleys is enhanced tenfold by irrigation. The cultivation of vines in the Bouches-du-Rhône has been of considerable importance and is the most profitable of all productions. Unfortunately phylloxera has caused enormous losses since the year 1866, and has destroyed thousands of acres of vineyards. The area of vines under cultivation in the year 1866 was about 125,000 acres, while in 1872 the area was reduced to 70,000 acres through the destruction of this pest.

Among the various experiments carried out to cure the phylloxera, the system of M. Faucon has, after eight years trial, proved the most efficacious. It consists simply in submerging the ground of the vineyard with water to a depth from 4 to 6 inches for a period of thirty days successively during autumn, or forty-five days in winter. The main precaution consists in being careful that the entire surface of the ground is kept covered with water during the whole period of the thirty or forty-five days. The submersion is supposed to drown the insects at the roots of the vines. But if the surface of the ground, for even a short time, during the period of submersion should not be covered with water, the air penetrates the soil and revives some of the insects, which subsequently propagate and spread rapidly. This discovery of M. Faucon has hitherto been successful in nearly all cases when the system has been properly carried out, not only in absolutely preventing the phylloxera, but also in reviving vines which are attacked, providing they are not too much injured. A few cases occurred in the summer of 1876 when the phylloxera was discovered in vineyards, treated on M. Faucon's system, adjoining other vineyards not so treated full of phylloxera. It may be remarked that in the spring of that year some very severe frosts greatly injured most of the vines in the Bouches-du-Rhône, resulting in a

yield of wine considerably below the average quantity. An opinion is entertained, by some agricultural authorities in France, that the vines, growing for several years, become exhausted and enfeebled, and the land impoverished, until they are in a state which attracts the insects to prey upon them. However feeble at the commencement the phylloxera propagates and spreads rapidly. In support of this opinion it is contended that it is not so much in submerging the ground with water to drown the insects at the roots, which does not destroy all the insects in the stalks of the vines, as the beneficial effects to the vines from the deposit of the valuable sediment and action of the chemical matters held in solution of the water mostly drawn from the river Durance, which acts as a manure and stimulant. Although there are no satisfactory experiments to show how much of the beneficial effects of irrigation can be attributed merely to the water supplying moisture to the land and crops, or to the matter in solution[1] and mechanically suspended in it, yet it is well known that the waters of the Durance produce more satisfactory results than the waters of some other rivers, as, for example, the Sorgues. The clear water of that river can be had by the proprietors almost gratis, nevertheless they prefer to form associations, and, at a considerable expense, to obtain water from the river Durance. If this opinion, as to the virtue of the matter in the water being a preventative of the phylloxera, should be borne out by facts, the vineyards, after existing a limited number of years, will probably, notwithstanding the cost and time, namely, three years, required to establish a vineyard, be ploughed up and other crops cultivated on the land for a time; thus new vineyards would be planted at shorter intervals than is now the custom. In some districts, where vines were cultivated, the ground was either so hilly or of such a porous sandy nature that submerging the ground was not practicable. In other districts no available means for obtaining water existed to submerge the ground. In most such cases the vines have either perished or are greatly deteriorated, and are only maintained by means of costly chemical manures applied to their roots.[2]

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[1] Some important researches in France on the application of water for irrigation, is by M. Hervé Magnon, entitled "Expériences sur l'emploi des eaux dans les irrigations." 2e édition. Paris, Dunod, 1869.

[2] The injurious effects of the phylloxera to the prosperity, and doubtless to the traffic of the country, have caused the Paris, Lyons, and Mediterranean Railway Company to supply chemical manures—and to publish instructions for their use—for the purpose of curing the vines attacked with the pest.

The benefits derived from irrigation in the department of the Bouches-du-Rhône are very important and extensive, nevertheless, the system is not carried out to the extent necessary fully to develope the resources of the water available for that purpose. The cost of irrigation, by the numerous canals, varies considerably; the extremes being from 6*d.* to more than 26*s.* per acre per annum. But the low prices result, in most cases, from exceptional causes and the advantages obtained formerly by concessions when the canals were under financial difficulties. Moreover, the supply of water is limited—it cannot always be regularly obtained. For a legitimate and proper supply the prices charged by the two modern canals, Marseilles and Verdon, respectively, about 26*s.* and 22*s.* per acre, may be considered the standard prices. The quantity of water given at these prices is equivalent to a flow of 1 litre per second per hectare during the irrigating season of one hundred and eighty-three days, sufficient to cover the ground to a total depth of 62½ inches, with 20,681 cubic yards of water. The charge for the water on the Henares and Esla canals in Spain, in comparison for the same quantity of water, would, respectively, be at the rate of 55*s.* and 40*s.* per acre per annum. But those canals only give water for twelve irrigations, each respectively 916 and 850 cubic yards, equivalent to a total quantity of 10,987 and 10,203 cubic yards of water per annum. The annual cost of irrigation is therefore reduced proportionately, viz., to the rate of 29*s.* and 23*s.* per acre. The total area irrigated in the Bouches-du-Rhône is about 87,000 acres, of which 13,000 acres are irrigated directly by water taken from the river Rhône, leaving 74,000 acres irrigated by the canals. The quantity of water conceded to the existing canals is about 71·9 cubic yards per second, which is sufficient to irrigate 137,500 acres. There is therefore sufficient water conceded to the existing canals to irrigate about 63,000 acres of additional land. The reasons why the system is not more fully developed are various. The old canals, such for example as the Crapponne, cannot be administered in a manner fully to develope their resources in consequence of the conflicting interests of the various owners or persons interested in them by virtue of the onerous concessions of former days. The water, in some instances, has to be supplied to land whose owners formerly bought the right for allowing the canals to be executed through their property, and to others who bought the right to use the water at a very low price. The result is that the annual revenue is barely sufficient to maintain the canals and works. The maintenance of the canals, taking their water from the Durance is

another reason. This river, which supplies about 80 per cent. of the water of the canals, is sometimes very muddy, thus causing the canals to silt up, and necessitating considerable annual expenses to clean them out. A difficulty is also encountered by proprietors, possessing land, sometimes of small area at a distance from the main canal, in obtaining a right to construct a connecting canal through the properties of others, and in disposing of the waste water. There is likewise the question of the necessary outlay in establishing the system of irrigation; sometimes the proprietor is not disposed to lay out the money, and the tenant is neither able nor willing to improve a property which does not belong to him. In many cases the holdings are of small extent, and it would not pay to make a long connecting canal to the land, even if there were no hindrances from intervening landowners. The difficulties inherent to the old canals would seem to point out the advisability of constructing new ones. This cannot be done for irrigation purposes, inasmuch as the whole of the water which the Durance is capable of supplying throughout the irrigating season is already more than conceded. The quantity of water flowing down the river, at the ordinary lowest summer level, is estimated at 2,540 cubic feet per second. The quantity already conceded in the departments of Bouches-du-Rhône and Vaucluse is 2,900 cubic feet per second. Excepting a limited area the ordinary level of the water of the river Rhône is too low to be of use for irrigating by gravity regularly throughout the season, even the lower portions of land situated in its course through the department of the Bouches-du-Rhône. In the case of the Marseilles canal some of these difficulties do not exist. That canal is well managed, and there are ample funds to execute the connecting canals and works to the limit of the properties to be irrigated. The result is that a charge for the water at the rate of 26*s.* per acre per annum is easily obtained, which is considerably higher than the charges of most of the other canals, and the whole available water of the canal for irrigation is nearly subscribed for. To meet some of the difficulties for extending the use of the water of the old canals for irrigation, numerous syndicates and independent companies have been formed from time to time, which have greatly helped to increase the area under irrigation as it now exists. The Government has also been liberal in granting subventions for the improvement of the Durance and its dykes, and for the construction of some of the canals.

In 1874 the Government decided to invite competition for a period of five years, open to all, and to reward those whose

system of irrigation was considered by a jury,[1] the best in the department of the Bouches-du-Rhône. It is anticipated that this will evoke a spirit of emulation in the department and country generally, as is the case in granting prizes in England for agricultural implements, machines, stock, and produce.

The following is the *arrêté* of the Government:—In order to encourage efforts tending to improve agriculture, principally in developing cultivation by irrigation, considering the losses caused by the phylloxera and necessity of transforming or of increasing the production of irrigated land, rewards will be accorded in the department of the Bouches-du-Rhône in 1875, 1876, 1877, 1878, and 1879, to agriculturists, proprietors, or farmers, who shall have utilised in the most intelligent manner the water of the different irrigating canals. The rewards will be given as follows:—

FIRST CATEGORY.

To properties consisting of more than 10 acres of irrigated land—

	£.
1st prize, a gold medal and	40
2nd „ a silver medal, large size, and . . .	28
3rd „ a silver medal and	24

SECOND CATEGORY.

To properties consisting of 10 acres and under—

	£.
1st prize, a gold medal and	24
2nd „ a silver medal and	20
3rd „ a bronze medal and	12

An object of art can be awarded to the winner of the first prize of one of the above categories, acknowledged to be superior, or judged to be specially noted for the economical management of the water in practical irrigation. In the case of an object of art being awarded the gold medal destined for the first prize will not be given.

This communication is accompanied by a series of maps and drawings from which Plates 5 and 6 have been compiled.

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[1] The map and plan annexed to this Paper, also some of the details, were obtained from the report of the jury for 1875. Sur le concours ouvert en 1875, pour la meilleur emploi des eaux d'irrigation, par J. A. Barral, sécrétaire perpétuel de la société centrale des agriculteurs de France.

No. 1,512.—"The Works of the Bilbao Iron Ore Company, in the Province of Biscay, Spain." By FREDERICK CADOGAN BARRON, Assoc. Inst. C.E.

ABOUT the year 1870 the hematite deposits of the North of Spain began to attract the attention of English and French manufacturers, and towards the end of 1871 the Bilbao Iron Ore Company was formed in London for the purpose of constructing a railway and port for the carriage and shipment of the produce of extensive mines in the rich iron ore districts of Somorrostro and Galdames, in the province of Biscay. Mr. Edward Woods, M. Inst. C.E., having been appointed Engineer-in-Chief, engaged the services of Mr. George Higgin, M. Inst. C.E., as Consulting Engineer in Spain, and of the Author as Resident Engineer, to carry out the works under his direction.

The mines of Biscay present evidence of having been extensively worked by the ancients. Pliny, the naturalist, was undoubtedly aware of the large deposits of iron ore in the Biscayan provinces. In his work on natural history (Book 34) he mentions a mountain upon the Cantabrian coast entirely of iron, which from its general designation is presumed to be Triano, now more familiarly known as the Somorrostro mines. From this it may be assumed that these mines have been known for about eighteen hundred years.

The district in which the Bilbao Iron Ore Company's works have been constructed is mountainous, well wooded and watered. The works were commenced early in January 1872; but within three months after cutting the first sod of the railway, the Carlist revolution broke out, and caused great delay in the execution. They were, however, pushed on as opportunity offered, and were so far finished as to permit of the passage of the first engine through to Galdames on the 15th of February, 1875. Shortly after, the Carlists, finding they were not going to reap any benefit from the exportation of the mineral, ordered the complete stoppage of the works, and this continued until the declaration of peace in March 1876.

The railway, nearly 14 miles in length, has been constructed for mineral traffic only. It commences on the sea-shore, at an altitude of 9 mètres above ordinary high water, and passing immediately through the Sestao hill by a tunnel, 697 yards in length, rises, with gradients of 1 in 45, 47, and 55, to the summit,

at kilomètre 7, to an altitude of 360 feet. It has a double line of way of 3 feet 9 inches gauge. From kilomètre 7 to the termination of the line the railway is practically horizontal, and for the greater portion of the distance skirts the sides of the mountains contouring the different valleys (Plate VII.). The length of straight line is 11,043 yards, of curves 13,463 yards, the total being 24,506 yards. The curves vary from 197 feet to 984 feet radius. The maximum gradient is 1 in 45, the minimum 1 in 500. It was originally intended to construct a double line for the first 7 kilomètres only; ultimately it was decided to construct the entire line for a double way, and to lay the heavy traffic road, or "down line," with steel rails, and the light traffic road with iron rails. An objection to doubling the line after a single way had been opened would have arisen from the necessity of blasting out the sides of the deep cuttings, which would have been almost impossible without impeding the traffic. The railway was divided into two contracts, excluding permanent way and ballasting. The first section, from the commencement to kilomètre 7, including the Sestao tunnel, was let to Mr. Robert Roberts. The second section, extending from kilomètre 7 to the end of the line, was let to Mr. John MacLennan. Great credit is due to the contractors for the energy displayed, and their perseverance in overcoming all the obstacles occasioned by the Civil War. The ballasting and plate-laying has been done by the administration.

In a mountainous district, such as that through which this line passes, the work of locating the centre line requires considerable study. In the present case a series of base lines was run as near as possible to the intended course of the railway. Upon these base lines cross sections were taken at every 65½ feet apart, and the levels so obtained were written upon a general setting-out plan, and the curves adjusted to suit the ground. This, in some places, had to be done with the greatest nicety, as owing to the steepness of the mountain-sides a change of 4 or 5 feet in the position of the centre line would frequently make the difference between a deep cutting or a lofty embankment.

The earthworks consisted of a series of deep, short cuttings through the spurs of the hills, nearly entirely through rock, with lofty but short embankments crossing the ravines. Several of these embankments are upwards of 80 feet in height. All the higher banks have been made of rock, and have given but little trouble from settlement. Four classes of rock have been cut through, viz., blue shaley limestone, compact grey limestone, sandstone, and brown iron ore.

The cuttings on the first section were mostly through the softest blue shaley limestone. On the second section the blue limestone is hard, compact, and in some cuttings harder to drill than the grey limestone.

Sandstone only occurs in limited quantity at kilomètre 15. The standard width of the cuttings at the formation level is 25½ feet, that of the embankments is 26¼ feet. Whenever more material was required for the adjoining embankments the cuttings were widened, in preference to making side cuttings. The total quantity of excavation upon the first section, excluding stations, is 229,000 cubic yards; upon the second section 993,000 cubic yards; a total of 1,222,000 cubic yards, or an average of 87,780 cubic yards per mile. The cost was £7,688 per mile. The price paid per cubic yard was about 2*s.* 3½*d.* This rate included all classes of rock and earth transported any distance within about 220 yards. From the above figures some idea of the difficult nature of the ground may be formed, bearing in mind that the second section consists of a series of curves of 260 to 330 feet radius. The amount of excavation would have been reduced by greater use of retaining walls, but it was decided to avoid them as much as possible, because, owing to the precipitous nature of the ground, the walls must have been of great height and strength. Besides, the stone obtained from the cuttings was considered hardly fit for lofty walls, and stone must therefore have been transported from a distance.

The bridges and culverts, although numerous, are practically of small importance. The former are all over bridges, with the exception of one, and are principally for parish roads. The turnpike-road bridges are constructed of rubble masonry, with ashlar quoins and brick arch in cement. The parish-road bridges are of rubble masonry, with ashlar quoins and timber superstructures. The river Galindo is crossed by a two-arched bridge, each arch of 16½ feet span; it is built of snecked rubble masonry, with ashlar quoins and brick arches; the central pier and abutments are supported upon piles 36 feet long, surrounded at their top with a bed of hydraulic concrete 6½ feet thick. They support four lines of rails. The culverts are of the ordinary type, varying in width from 1½ foot to 16½ feet; most of them are of considerable length.

There are eight tunnels. The first five, together 1,198 yards long, are of a larger section than the last three, which are 158 yards long. The first five tunnels are on the main line, and are built for a double line. No. 6 is for the diversion of the river at kilomètre 17,

and is 10 feet wide. The last two are for branch lines at Galdames mines. Tunnel No. 1 (Sestao) passes through a shaley limestone, which required blasting throughout. On the 18th of April, 1872, the contractor commenced driving the heading at the west end, and upon the 12th of the following October at the east end. The two headings met on the 15th of June, 1873. Operations were conducted from the two ends only, and in two sections, the upper section being kept about 65 to 85 yards in advance of the lower. The height of the upper gallery was 6½ feet, of the full section of the tunnel. The excavation was carried forward in three shifts at each end, working eight hours each. The average rate of progress, when free of difficulties caused by the Civil War, was 3¼ feet per day. Blasting was first done with common powder; but the ventilation became imperfect, and dynamite was subsequently employed, without having recourse to artificial ventilation. From the east entrance the gallery was driven 280 yards, and from the west entrance 416½ yards, and at these distances no ill effects were felt from insufficient ventilation. Dynamite was first employed at 213 yards from the west entrance. Table I. in the Appendix shows the comparative value of the ordinary blasting powder and dynamite, as obtained in the district, at a time when the works were free of molestation from the Carlists, and when the sub-contractor was using powder at the east end and dynamite at the west end. From this table it will be seen that the work done by 2·2 lbs. of dynamite was equivalent to 6·6 lbs. of ordinary blasting powder; but that, in point of cost per cubic yard of excavation, powder was nearly 5*d.* cheaper than dynamite. The dynamite was manufactured and supplied by the "Sociedad Española de Dynamita," at Galdacano, 6 miles from Bilbao. The fuse used was supplied from the manufactory of Messrs. Bickford and Company at Bilbao. After the excavation of the tunnel was completed, the action of the air caused the rock to disintegrate, and there was every appearance that in the course of a few years it would be necessary to line it. The Directors accordingly decided to avail themselves of the stoppage of the works, caused by the Civil War, to line it throughout before opening the railway for traffic.

Tunnels 2, 4, 5, and 6 have been cut through a harder description of limestone, and have only required lining in a few places. No. 3 was chiefly through soft sandstone containing large boulders of limestone, for which reason it became necessary not only to line but to support it with timber during construction. Nos. 7 and 8, which are 9¾ feet wide and 11½ feet high, have been cut through clays and the debris of old mines, and have been lined with stone.

The permanent way consists of Vignoles rails, weighing 56 lbs. per lineal yard (Plate 8), spiked to transverse pine sleepers obtained from the Landes in the South of France. The rails have been further secured by three wrought-iron sole-plates to each rail on straight sections, and by four on curves; these provide additional bearing surface to the rails, and tend to prevent the rails being forced out of gauge. The experience of the few months during which the line has been opened for traffic has proved the necessity of such sole-plates and the desirability of increasing their number, especially for the outer rail. On several of the sharpest curves, before the locomotive engines acquired a certain amount of play in their bearings, the outside rails were pushed outwards, especially where the rail was simply spiked to the sleeper. In one out of every three of the sole-plates the spike-holes are nearer together, so as to correspond with the notch at one end of each rail, to prevent the rail travelling. The lips of the sole-plates were hammered down upon the rails when fixed. Steel rails would have been adopted for both lines, but when the contracts were made the import duties on steel rails were upwards of £6 per ton, and the tariff for iron rails only £3 5*s.* per ton. Shortly afterwards the Spanish Government conceded to the Company permission to introduce steel rails and wagons duty free. The rails were bent while hot to the requisite curves, and those intended to form the inner rails of curves were cut to the proper length. The Author can testify to the great advantage of this principle in laying the road. Not only is expense saved in cutting the rails, but the tendency which a rail bent cold has to become straight is entirely obviated. Any little difference, either in the cutting of the rails to their proper lengths or in the setting out of the curve upon the ground, tending to cause the joints to overrun one another, is easily corrected by exchanging an interior rail for an exterior one, or *vice versâ*. The radius, together with the letter L or S to indicate inner or outer rail, was stamped upon each rail, and the plate-layers had, consequently, no more trouble in laying the curved than in laying the straight road. A list was supplied to the storekeeper beforehand showing the number of each class of rails to be forwarded in rotation. The price paid to the contractor for laying the road, including packing, &c., was about 11½*d.* per lineal yard. This price included discharging the wagons and the haulage of the materials for a distance of 220 yards.

The sleepers, 7 feet 10 inches long by 8¾ inches wide, by 5 inches thick, are spaced at unequal distances, on the straight road with

nine sleepers to each rail of the standard length of 24 feet, and with ten sleepers on the curved portions. An alternative plan has been adopted for a short distance, by way of experiment, in two different parts of the road, consisting of a combination of longitudinal and transverse sleepers. The majority of the sleepers were injected with sulphate of copper. The rails of both lines are fish-jointed with plates 18 inches long, $2\frac{3}{8}$ inches wide, and $\frac{11}{16}$ inch thick; they are punched with four oval holes $\frac{7}{8}$ inch by $1\frac{1}{4}$ inch. The bolts and nuts are of best Staffordshire iron; the bolts are $\frac{3}{4}$ inch in diameter, with an oval part formed under the head, $\frac{3}{4}$ inch by $\frac{1}{8}$ inch, to prevent their turning round in the fish-plates. Table 2 in the Appendix gives a statement of the cost and weight of the materials.

The ballast is 1 foot 8 inches in depth. That for the first section was chiefly of hard grey limestone, broken by one of Blake's stone-crushers; it was laid in three layers; the first, broken to about 3 to 4 inches square, was covered with a layer a few inches in depth of softer limestone broken small for packing the sleepers, and then boxed up with limestone broken to pass through a ring 2 inches in diameter. Upon the second section the cuttings yielded an abundant supply of good ballast.

The size of the stone-crusher used was 20 inches by 9 inches. The quantity of stone broken per day of ten hours was 78·5 cubic yards. The cost of getting and breaking the stone amounted at first to 1*s.* 10½*d.* per cubic yard, but this was materially increased by the constant delays caused by the Carlist War.

There are five stations, Sestao, Galindo, Bodovalle, Pucheta, and Galdames. At the Sestao station are the Company's offices, workshops, manager's and secretary's houses, stores, and other buildings (Plate 7). All the points and signals are worked from one box, with Messrs. Stevens and Son's interlocking apparatus, which the Author believes to be the first set of interlocking apparatus erected in Spain. The workshops are contained in an edifice 223 feet in length and 44 feet wide, divided into three compartments, comprising repairing shop, blacksmith's shop, and carpenter's shop. An ample stock of machinery has been supplied for general repairs to the locomotive engines, and for the construction and repair of wagons. The machinery is driven by a horizontal condensing engine. An engine-shed is arranged to hold seven large and seven small engines, with space for enlargement. It is intended to erect a small gas apparatus immediately beyond the workshops, for lighting them and Galindo station. The workshops are built of snecked rubble masonry, with sandstone quoins. Galindo station,

at the west end of Sestao tunnel, is merely a sorting station. Here all the ore-laden wagons are sorted upon the arrival of the trains, and left standing until the ore is required for shipment. This station has a shed to accommodate four engines, a turntable, and water supply. Bodovalle and Pucheta stations have been constructed for the reception of the campanil and vena dulce ores of the Triano mines. Each station is provided with extensive loading platforms, weighbridges, and sidings; beyond Pucheta station an engine, turntable, and water tank have been fixed. The Galdames station is supplied with offices, stores, turntable, workshop, water supply, a residence for a mine manager, blocks of cottages, and barracks for the accommodation of the foremen and workmen employed at the mines.

The harbour works consist of a pier for the shipment of ore; a canal 3,280 feet in length and 328 feet wide, dredged to a depth of 18 feet below low water; a stage for discharging the dredging barges and coal, and a stage with a 15-ton shearlegs for discharging materials and fixing mooring buoys.

The pier for the shipment of the ore, 902 feet in length, commences with a curve of 197-feet radius, and admits of four vessels being loaded at one time, of the class generally used for the iron ore trade in the Bilbao river. The rail-level is 29½ feet above ordinary high-water mark, which height has proved amply sufficient for loading the steamers employed in this trade; but in order to provide for vessels having high bulwarks, an extra shoot is about to be provided. As the height is too great to permit the loading of sailing vessels at low water with safety, a special shoot is in course of erection upon the stage for the discharge of material, which will enable the small craft to be loaded at any state of the tide without risk. The Author is of opinion that four vessels of 800 tons each, and one sailing vessel, can with the present arrangements be easily loaded per day, or say 3,500 tons altogether.

The pier is of wood, and was erected by contract by Mr. Peter Shade, but as wooden structures in the river Nervion suffer much from sea worms, it is intended to build a concrete wall along the face to the height of the sailors' gangway, making thus a permanent pier, and filling in the back with the sand dredged from the canal in front. The piles are of Memel timber, 13 inches square, driven to a depth of at least 33 feet below low water, and until they were capable of sustaining a minimum weight of 15 tons, calculated by the formula

$$x = \frac{B^2 h}{(B + P) e};$$

where x = minimum resistance of 25 tons; B = weight of monkey; P = weight of pile; h = fall of monkey; e = distance driven by the last blow. Each pile was numbered, and a diagram kept giving its sustaining power and history. All the piles were driven by hand-power machines, having monkeys weighing 20 cwt. The superstructure is principally of French pine, obtained from the Landes, and injected with sulphate of copper.

Each ship's berth is provided with two shoots, actuated by winches fixed upon the upper platform. The shoots are arranged to receive the contents of two wagons, weighing about 10 tons, at the same time. Owing to the ground swell along the face of the pier when the sea outside is rough, an alteration has been made in the mode of raising and lowering the shoots, which is now done by a balance weight suspended at the back of the pier, in such a manner that the weight can be dropped and the shoot hoisted almost instantaneously. The time required to hoist the shoot from ordinary loading position, as altered, is forty-five seconds, and rather more than two minutes is required to lower it to the same position. Two men are needed to lower the shoot, and one only to raise it. The present arrangement consists in fixing the shoot at the upper end, and connecting the extreme point, by means of two $\frac{5}{8}$-inch chains passing over pulleys fixed above, to a balance weight of two large cast-iron chains and weight (Plate 8). The ever-varying position of these chains and weight compensates for the increase and decrease of weight of the shoot caused by the variation of the angle of elevation.

The ore is dropped from hopper wagons into a large wooden hopper, lined with iron bars $\frac{1}{2}$ inch thick, to the mouth of which the iron shoot is attached to conduct the ore to the ship. The largest amount of ore shipped upon any one day up to the present time has been 3,300 tons. The greatest despatch yet given to any one vessel was 150 tons in thirty minutes. An ample supply of buoys and bollards has been fixed for mooring the vessels; the buoys are secured to piles 9 feet long, screwed in from 10 to 16 feet below the permanent bottom of the canal. A service of fresh water has been provided along the pier, for the provision of vessels and for protection against fire. The water is obtained from springs in the tunnel, and pumped into a reservoir, with a capacity of 82,500 gallons, built in the side of the hill at 33 feet above the rail-level on the pier.

The dredging consists of cutting out the canal along the face of the Company's property. Approximately the quantity to be dredged is 785,000 cubic yards of material. The work is being done by

one of Messrs. Tilken and Company's steam central-ladder dredgers, capable of dredging to a depth of 26 feet, and lifting 800 tons per day. The shell of the dredger is of iron, divided into eleven water-tight compartments; its length is 110 feet, width 17 feet 6 inches, depth 8 feet, and draught of water 4 feet. The machinery is driven by two high-pressure engines, each of 18 HP., and the overhead shaft by two strong double belts. The length of the ladder between the centres of the tumblers is 52 feet 10 inches. It works thirty buckets, each having a capacity of 0·33 cubic yard. The average consumption of fuel during seven months has been 18½ cwt. per working day, but this cannot be accepted as a fair criterion of cost, as, owing to the scarcity of barges and the means of discharging them, the dredger has not been worked up to its full capabilities. The crew consists of one captain, earning £15 12*s.* 6*d.* per month; one engine-driver, earning £7 16*s.* 3*d.*; one stoker, earning £6 5*s.*; and five sailors, each earning £4 11*s.* 8*d.*; the total amount for wages being £52 12*s.* 1*d.* per month.

Several classes of barges have been tried; the one ultimately adopted has been a hopper-decked barge, of French pine, to hold 50 tons of material, 39½ feet long and 17½ feet wide (Plate 8). The advantage of this form is that the water brought up by the dredger flows over the sides of the barge when it is nearly full, leaving the sand almost dry. It will likewise float although the internal compartment may be filled with water. The barges were made at Bayonne, and sent over in pieces to Bilbao. Their cost f. o. b. at Bayonne, is £117 11*s.* 5*d.*; freight, duties, and erecting in Spain, £85 11*s.* 2*d.*; total cost, £203 2*s.* 7*d.* The Company possess eight 50-ton and six 30-ton barges. The last six were constructed in the Bilbao river.

The material dredged (sand and mud) is conveyed in the barges to the discharge stage (Plate 8), near the centre of the station, and lifted to a height of 21 feet above high water ordinary spring tides. The hoisting machinery is worked by shafting, driven by one of Robey and Company's 12-HP. portable engines. The shafting drives two sets of gearing, working each two grooved winding drums, 16 inches in diameter, with ⅝-inch chains coiling in contrary directions, so that whilst one jib is lifting the other is lowering. The skips hold 22½ cubic feet of material, weighing 1,700 lbs., and discharge their contents into tip wagons working upon a platform immediately below. The weight of the empty skip, is 485 lbs., making a total weight of 2,185 lbs.

In a day of ten hours, six hundred laden skips are hoisted. The spoil is tipped into the original river channel, and the base of the

bank is protected by a toe of rubble run ahead of the tip; the face of the toe will be eventually pitched with squared blocks. A statement of the actual cost of dredging during seven months is given in Table 3 in the Appendix.

The mines belonging to the Company are, in the district of Galdames:—

	Acres.
1. La Escarpada	111
2. La Cenefa	45
3. El Berango	67
4. Dudosa	111
5. Tardia	91

In the district of San Pedro de Abanto:—

6. Moruecos	148
7. Cerrillo	10
8. Vulcano	74
9. Convenio	62
10. Las Venerillas	91
Total area	810

Of those at Galdames only the Berango mine has been opened, and is now being worked. Here the lode apparently extends from north-east to south-west, and it can be traced for a distance of about 1,640 yards. The ironstone crops out of the side of the mountain in vertical cliffs, one of which has an escarpment of 55 yards. At about the centre of the present workings the lode of ore has been traced to a width of 306 yards at the railway level. There is enough ore above the railway-level to employ the resources of the Company for many years. Generally there is but little covering, and, a large portion of this having been removed, the ore is being worked in steps. The ironstone, a hard brown hematite, is blasted with dynamite and common powder in large masses, which are then broken up with steel wedges and hammers, and tipped through shoots into heaps at the railway-level, or loaded into wagons direct.

The cheapest and most convenient way of reducing the larger blocks to a manageable size is to insert a third or a half of dynamite cartridge into a hole of from 1 inch to 2 inches in depth upon the upper face of the block to be broken. A block weighing 1 ton or 2 tons will thus be shaken so that a few blows of a hammer will break it up.

A climbing railway has been partially constructed for taking the

wagons up to the different levels, and this when completed will facilitate the manipulation of a large quantity of ore, and save considerable expense in handling. A self-acting incline plane has also been constructed up to the first level with a gradient of 1 in 6. It is worked by a chain and underground pulley (Plate 8), and so far has given great satisfaction. The length of the incline is 120 yards. The trains consist of four wagons ascending and four descending; the weight of the ascending train being 11 tons, and of the descending one 31 tons.

The surface earth is removed by bridges and shoots, and tipped into the valley upon the opposite side of the railway. The following are analyses of the Galdames ore:—

——	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Ferric oxide (F_2O_3). . . .	78·800	79·200	76·000	78·350	81·740
Silica.	5·550	1·700	7·650	7·220	4·200
Alumina.	3·500	6·800	5·800	2·180	2·040
Manganese oxide	0·651	2·880	0·830	0·030	0·730
Combined water	11·653	9·672	10·128	11·550	10·300
Sulphuric acid	0·068	0·620	0·340	0·020	0·010
Lime and magnesia. . . .	Traces	Traces	Traces	0·300	0·680
Phosphoric acid.	None	None	None	0·030	0·030
	100·222	100·872	100·748	99·680	99·730
Loss in drying	0·660	1·800	1·600	..	..
Metallic iron	55·160	55·440	54·200	54·840	57·200

The absence of phosphorus and sulphur renders this ore eminently suitable for the manufacture of pig iron for conversion into Bessemer steel; but it requires careful selection to free it of the silicious matter. The Moruecos mine, owing to its distance from the line and limited extent, has been abandoned. From kilomètre 8·500 to kilomètre 10·500 the Galdames railway skirts the base of the Somorrostro mines; and for the accommodation of this district two stations have been provided. The first, at kilomètre 8·600, called Bodovalle, is almost overhung by a mass of the best ore. At this station provision is made for the loading and removal of about 2,000 tons of ore daily. At Pucheta, the second station, works are in course of construction that will provide for receiving and despatching upwards of 2,000 tons of ore per day. The ore is at present carted to these stations; but a wire tramway is being fixed

from one mine, and this will probably be followed by one or two more tramways of a similar character from adjacent mines. The mines of the Somorrostro district yield three different classes of mineral, viz., campanil, or red hematite; vena dulce, a rich soft ore; and rubia, or brown hematite. Up to the present time the first has been chiefly sought after by the English and Belgian manufacturers, and for many years past an extensive trade has been carried on in this article. In the Appendix, Table 4, will be found a statement of shipments prior to the outbreak of the Carlist War. Table 5, prepared from the official mineral statistics of the province, gives the quantity of ore of all kinds exported since the year 1860. The campanil and rubia ores are mostly worked in open cast, the vena dulce by galleries. The comparative value of these ores may be taken as follows:—

——	Campanil.	Vena dulce.	Rubia.
	Per cent.	Per cent.	Per cent.
Metallic iron	50 to 55	54 to 62	52 to 58
Silica	1 „ 7	1 „ 3	3 „ 10
Sulphur	Traces	Traces	Traces
Phosphorus	„	„	„

The campanil ore requires to be blasted, and the cost of extraction is about 1*s.* per ton, according to situation. This ore is found chiefly in pockets in the limestone, but in some places it appears almost in mass. It has hitherto been carted to the Ortuella station of the provincial railway, a distance of 1¼ mile, and was thence conveyed by railway to the river at the "Desierto," and tipped through shoots into vessels. The railway was constructed in the year 1866, expressly for the transport of this ore, by the Provincial Government, to whom it still belongs; it is a single line of 5 feet 3 inches gauge.

In 1866 the quantity of ore shipped by this railway was 32,107 tons, and it increased year by year to 205,000 tons in 1871.

The vena dulce ore has hitherto been extracted in small quantities by means of galleries; its sale has been confined to the North of Spain and the South of France, for reduction in charcoal furnaces, for which it is admirably adapted. This ore does not generally require the use of powder for extraction, being principally got with picks. The value of this ore at the entrance to the gallery

is about 4*s*., and placed on board ship from 12*s*. to 15*s*. per ton. The rubia ore has not been extensively worked; it is much harder to get, and more expensive in breaking up and selection, than the campanil; but it is more suitable for the strong coal and high furnaces in England than the latter ore. The Triano mines are held by small proprietors, who are constantly in litigation, and who work their mines wastefully and unsystematically. The Bilbao Company has made arrangements for working some of the concessions, and is in treaty for others. Spathic ore has likewise been found in the district, but it is not known to exist in any large quantity.

The rolling stock consists of six large locomotive tank engines, made by Messrs. Kitson and Company, of Leeds; three small locomotive tank engines, made by Manning and Wardle; five hundred 5-ton mineral hopper wagons, and eight 5-ton ballast wagons, supplied by the Darlington Wagon Company, Mr. Edward Eastwood; and two 5-ton mineral tip wagons, supplied by the Ashbury Carriage Company.

The large locomotive engines have ten wheels, six coupled, with a four-wheeled bogie in front. The leading pair of driving wheels are without flanges. The principal dimensions of these engines are: Diameter of cylinders 14 inches; length of stroke 20 inches; heating surface of the fire-box 70 square feet; grate area 11·5 square feet; external diameter of the boiler 3 feet 8 inches; length of the boiler 10 feet; number of tubes, one hundred and thirty-eight; heating surface of the tubes 652 square feet; diameter of the bogie wheels 2 feet; diameter of the driving wheels 3 feet 6 inches; distance from centre to centre of the bogie wheels 4 feet 8 inches; distance between the centres of the driving and trailing wheels 7 feet; distance between the centres of the leading and driving wheels 4 feet 2 inches; capacity of the tank 550 gallons; capacity of the coal bunker 30 cubic feet; weight of the engine 26 tons 18 cwt. 2 quarters; water in the boiler, estimated at 2 tons 15 cwt.; water in the tanks 2 tons 9 cwt.; fuel 15 cwt.; weight of the engine when laden 32 tons 12 cwt. 2 quarters. The locomotives are capable of taking up the incline trains composed of forty empty mineral wagons, representing a gross load of 110 tons; but for the better regulation of the service they are only required to take up trains of thirty wagons. The gross weight of the descending trains, excluding the weight of the engine, is, load of ore 150 tons, thirty wagons 82 tons, total 232 tons.

With thirty wagons attached, when the rails are dry, the curves

offer so great a resistance that it is necessary to apply steam in descending the incline; but when the rails are wet all the brakes of the wagons have to be pinned down, and the train controlled by the engine brakes. These engines, which are fitted with Adams's patent bogie, traverse the 263-feet curves with facility, and even the 197-feet curves when running bogie first. They were built to suit curves of a minimum radius of 263 feet. Upon sharp curves, when running bogie first, they do not injure the road so much as the light four-wheel engines, although the fixed wheel base is greater; apparently the large engines, with the guiding action of the bogie, are led gently on to the outer rail of the curves, along which they continue to grind, whereas the light four-wheel engines oscillate from one rail to the other. The guiding action of the bogie has been demonstrated by the fact that, upon several occasions when the engine has been run backwards, the outer rails on the sharp curves have been pressed outwards, and the wagons, which have 1 inch less tread of tire than the engines, have dropped between the rails; but this has not occurred when running the engine bogie first. This bogie relieves to a great extent the wear of the flanges of the driving wheels; and the Author considers it superior to the ordinary, or even the Bissell bogie. After running barely 4,000 miles, the leading pair of bogie wheels of engine No. 1 had to be taken out, solely on account of the wear upon the flanges, whilst the flanges of the back wheels of the bogie and the drivers were almost untouched. In this case the front wheels have been exchanged for the back pair. The small locomotives are used only for shunting purposes and for service upon the pier. During the construction of the line they were found very serviceable in hauling the materials and ballasting, &c.

The mineral wagons are hopper-shaped, lined with iron, and arranged to carry 5 tons of ore. The framing is of oak, the upper work of pine, with one central wooden buffer at each end; but it has since been found desirable to supply spring buffers and drawbars. They are mounted upon springs having seven plates 3 inches wide by $\frac{3}{8}$ inch thick. The wheels are 2 feet 6 inches in diameter and 4 feet 9 inches apart from centre to centre. The tires are of Bessemer steel, $4\frac{1}{8}$ inches wide by $1\frac{3}{4}$ inch thick on the centre of the tread. The doors are supported by three prongs worked by a handle from the side, in the same manner as many of the coal wagons upon English railways; but this system has been found unserviceable for the traffic of iron ore, and the door gear is now being modified.

The cost of land and works have been as follows:—

	£.	£.
Land	..	25,000
Earthwork	..	121,969
Tunnels:—		
Sestao	30,670	..
Other tunnels	17,132	..
		47,802
Bridges and Culverts	..	24,225
Permanent way:—		
Rails and fastenings	61,509	..
Sleepers	9,911	..
Ballasting	7,380	..
Plate-laying	3,200	..
		82,000
Telegraph and signals	..	2,430
Rolling stock:—		
Locomotive engines	17,170	..
Wagons	32,588	..
		49,758
Harbour works:—		
Sestao pier	26,000	..
Dredging and materials, stages	3,200	..
Buoys and sundries	2,500	..
Dredging and toe banks	8,482	..
		40,182
Stations and level crossings, buildings, and workshops	..	14,580
Works at mines	..	8,200
Machinery and fixed engines	..	6,493
Dredger and barges	..	10,622
		£433,261

One of the greatest difficulties in regard to the exportation of iron ore from the port of Bilbao is the bar at the entrance to the river Nervion, preventing the exit of vessels drawing more than 10 feet of water, except during spring tides. This, together with impediments and restrictions regarding the entrance and leaving of vessels, has given the port a bad name and increased the rate of freight. Table 5 in the Appendix, obtained from the chief pilot, shows the height of water upon the bar during the years 1873–75. The bar has nearly always two crests, situated from 200 to 330 feet apart, subject to constant change, with the channel through it frequently tortuous and shallow.

Early in 1872 there were twenty-four days when no vessel could enter the port, and fifty-one days when no vessel could depart. Various schemes have been suggested for the improvement of the bar, and breakwaters have been proposed by the late Mr. C. B.

Vignoles, Past-President Inst. C.E., and Sir John Coode, M. Inst. C.E.

Other works have been projected in the Bilbao district for the transport and shipment of the ores, of which out of 34 miles of railway, a length of 19 miles has been completed, and of 7 miles of wire tramways a length of $1\frac{3}{4}$ mile has been completed. A large quantity of ore is also carried by the Bilboa and Tudela railway from the mines at Iturrigorri and Ollargan. And in the years 1872–73 much ore was shipped from Dicido and the port of Castro, as also from Santander.

The communication is accompanied by a series of maps and drawings, from which Plates 7 and 8 have been compiled.

APPENDIX.

TABLE 1.—COST of the SESTAO TUNNEL in a PERIOD of ONE HUNDRED DAYS.

—	Rate per Day.	Gallery from East Entrance.		Gallery from West Entrance.	
		Proportion per cubic yard.	Total Cost.	Proportion per cubic yard.	Total Cost.
	s. *d.*		*s.* *d.*		*s.* *d.*
Foremen's wages. . .	4 2	0·082	0 4·10	0·095	0 4·75
Miners	2 8·3	0·893	2 4·83	1·304	3 6·10
Labourers	2 2	0·999	2 1·98	1·177	2 6·60
Smiths	3 9	0·054	0 2·43	0·063	0 2·83
Horses	4 2	0·069	0 3·45	0·126	0 6·30
	lbs.	lbs.		lbs.	*s.* *d.*
Powder	0 4·8	2·531	1 0·20	..	..
Dynamite	1 8	..	..	0·833	1 5·00
	Cost per cubic yard.	Powder 6	4·99.	Dynamite 8	7·58

The average lead was 127·92 and 568·52 lineal yards yards respectively.

In addition to the increase of distance of haulage on the west side, considerable expense was incurred for the drainage and removal of road at the tip head.

TABLE 2.—BILBAO IRON ORE COMPANY, LIMITED. COST of PERMANENT WAY LAID in POSITION.

Description.	Number of Parts.	Weight.	Weight per Kilometre in Tons. Single Line.	Price per Ton. F. o. b.	Value. F. o. b.	Duties. Per Ton.	Duties. Amount.	Charges and Freight. Rate 12s. 6d. per Ton.	Discharging Expenses. 1s. 7½d. per Ton.	Total.
Iron road.		lbs.	Tons.	£. s. d.	£. s.	£. s. d.	£. s.	£. s.	£. s. d.	£. s. d.
Rails	273·59	56·0	54·7	10 10 0	574 3	3 8 0	185 9	34 3	4 8 10	798 4 10
Fish-plates	274 pairs	14·3	1·7	10 10 0	18 8	Nil	Nil	1 2	0 2 10	19 12 10
Sole-plates, N.	262·	3·3	0·4	19 13 6	7 3	„	„	0 5	0 0 7	7 8 7
„ O.	670·	3·3	1·0	19 13 6	19 6	„	„	0 12	0 1 7	19 18 7
Bolts and nuts	1,096·	0·8	0·4	24 5 0	10 0	„	„	0 5	0 0 8	10 5 9
Spikes	5,480·	0·5	1·2	22 15 0	27 16	„	„	0 15	0 1 11	28 12 11
Total iron					656 15		185 9	37 2	4 15 7	884 2 6
				Each sleeper.		Each.				
Sleepers	1,327·	110·2	65·2	0 2 9·5	185 4	0 0 1·15	6 7	Nil	5 5 10	196 17 7
Haulage	Estimated at 10*d.* per ton per kilometre. Average distance 10 kilometres = 8*s.* 4*d.*									51 18 3
Laying	Cost 11*d.*·43 per lineal yard									52 1 8
Ballasting	3,510 cubic yards per kilometre of double line (deducting sleeper), 1,755 cubic yards for a single line of road at 2*s.* 6*d.*·58 per cubic yard									223 12 3
										1,408 12 3

		£.
Iron road	Total cost of single line per kilometre	1,409
	„ „ „ mile	2,268
Steel road	„ „ „ kilometre	1,481
	„ „ „ mile	2,386

TABLE 3.—COST per CUBIC YARD of DREDGING SESTAO HARBOUR during SEVEN MONTHS in 1876.

—	Dredging and Filling Barges.	Barging.	Discharging Barges.	Haulage and Tipping into Banks.	Formation of Toe Bank of Rough Stone.	Total Cost of Work.	Total Quantity Dredged.	Cost excluding Toe Banks.
	d.	*d.*	*d.*	*d.*	*d.*	*s.* *d.*	Cubic yards.	*d.*
May . .	2·10	2·10	2·29	3·25	1·72	0 11·5	6849·211	9·8
June . .	2·29	1·91	4·21	2·68	3·06	1 2·1	10511·873	11·1
July[1] . .	1·15	1·53	4·01	2·68	4·21	1 1·5	10987·135	9·3
August[2] .	2·87	1·34	3·63	2·48	2·10	1 0·4	12038·832	10·3
September	2·10	1·53	3·44	3·44	1·53	1 0·0	10863·005	10·5
October .	2·68	1·72	3·44	3·44	2·29	1 1·6	8776·615	11·2
November.	1·53	1·15	2·87	2·29	..	0 7·9	10927·621	7·9
Average .	2·10	1·61	3·41	2·89	2·13	1 0·2	70954·292	10·0

[1] No coal charged.

[2] Coal for two months charged.

TABLE 4.—EXPORTATION of IRON ORE from BISCAY.

Year.	Number of Mines Worked.	Number of Men Employed.	Quantity Exported.
			Tons.
1861	53	698	54,006
1862	42	570	69,350
1863	42	575	69,606
1864	67	1,045	118,573
1865	75	893	100,747
1866	76	824	88,497
1867	81	1,059	133,930
1868	77	1,124	151,693
1869	88	1,300	162,205
1870	75	1,285[1]	246,415
1871	..	..	268,457
1872	..	..	422,949
1873	..	..	386,074
1874	..	..	47,724
1875	..	..	32,354
1876	..	..	389,812
Total	..	..	2,742,392

[1] Men employed at the Ollargan mines are not included. 29,921 tons of ore were exported from these mines in this year.

TABLE 5.—HEIGHTS of WATER on the BAR at BILBAO 1873-1874-1875 in FEET.

Date.	January.			February.			March.		
	1873.	1874.	1875.	1873.	1874.	1875.	1873.	1874.	1875.
1	..	..	10·51	..	..	10·97	..	..	10·97
2	..	..	..	..	..	10·97	..	..	10·06
3	..	..	..	..	..	10·97	..	..	10·51
4	..	..	..	..	..	11·20	..	..	10·97
5	..	..	..	..	..	11·65	..	..	11·42
6	..	..	..	..	..	11·65	..	..	12·34
7	..	..	12·34	..	..	..	..	..	12·34
8	..	..	..	..	..	..	..	..	12·34
9	..	..	11·88	..	..	12·11	..	..	12·80
10	..	..	..	12·34	..	11·88	..	..	13·71
11	..	..	..	12·80	..	..	..	..	13·71
12	..	..	11·42	12·80	..	11·88	..	..	12·80
13	13·71	..	11·20	..	..	..	..	..	..
14	13·71	..	..	13·71	..	..	14·17	..	..
15	..	..	..	13·26	..	..	14·17	..	..
16	..	..	..	13·26	..	..	14·17	..	..
17	..	..	..	12·80	..	9·60	13·71	..	10·06
18	11·88	..	11·42	11·88	..	10·06	13·71	..	10·51
19	..	..	..	11·88	..	11·20	13·26	..	11·42
20	..	..	..	11·88	..	11·88	..	..	12·34
21	..	..	..	11·88	..	..	12·80	..	12·80
22	..	..	..	11·88	..	12·11	12·34	..	13·71
23	..	..	..	12·34	..	12·11	12·34	..	13·71
24	..	..	..	..	..	12·11	12·34	..	13·26
25	..	..	..	13·26	..	11·88	12·34	..	11·88
26	11·88	..	..	..	..	11·65	13·71	..	11·42
27	..	..	11·42	..	..	11·42	14·63	..	..
28	..	..	11·20	..	..	10·97	15·08	..	..
29	..	..	11·42	..	..	..	..	..	..
30	..	..	10·97	..	..	..	..	..	10·06
31	..	..	10·97	..	..	..	..	..	10·06

TABLE 5.—HEIGHTS of WATER on the BAR at BILBAO 1873–1874–1875 in FEET (*continued*).

Date.	April.			May.			June.		
	1873.	1874.	1875.	1873.	1874.	1875.	1873.	1874.	1875.
1	..	..	10·51	13·26	..	11·42	..	14·17	12·34
2	..	..	10·97	12·80	..	11·88	..	13·71	12·80
3	..	..	11·42	12·34	..	11·88	..	13·71	13·26
4	..	..	11·88	11·42	..	12·34	..	13·26	13·71
5	..	..	13·26	..	..	13·26	..	12·34	13·71
6	..	..	..	..	..	14·17	14·63	12·34	13·26
7	..	..	..	..	..	14·63	14·17	..	11·88
8	..	..	..	..	..	14·63	..	..	11·88
9	11·42	..	..	..	..	13·71	..	..	..
10	11·88	..	..	..	..	13·71	..	12·80	10·97
11	12·34	..	12·80	12·80	..	..	..	..	10·51
12	12·80	..	11·88	13·26	..	..	..	..	..
13	13·71	..	11·88	13·26	14·17	10·51	12·34	12·80	..
14	13·71	..	10·97	13·26	..	10·51	11·88	13·71	..
15	13·71	..	10·97	13·26	..	10·51	11·88	13·71	..
16	13·71	..	11·88	12·80	15·08	10·97	12·80	13·71	..
17	13·26	..	12·34	12·34	15·08	11·88	13·26	13·26	..
18	12·80	..	12·80	11·88	15·08	12·34	13·71	12·80	..
19	12·34	..	13·71	11·42	14·63	12·80	14·17	12·34	12·80
20	11·88	..	14·17	..	13·26	13·71	15·08	11·88	11·88
21	11·42	..	14·17	11·42	12·80	14·17	..	11·88	12·34
22	11·42	..	14·17	11·88	12·34	13·26	15·08	11·88	..
23	12·34	..	13·71	12·80	12·34	12·80	15·08	11·88	..
24	13·26	..	13·26	13·26	12·34	..	14·63	11·88	11·88
25	14·17	..	12·34	..	12·80	..	14·17	12·80	12·34
26	14·63	..	11·88	13·71	13·26	..	13·71	13·26	..
27	14·63	..	11·42	13·71	13·26	10·51	13·26	13·71	11·88
28	14·63	..	10·97	..	13·71	10·51	12·80	14·17	12·34
29	14·17	..	10·51	12·80	13·71	10·51	12·34	14·63	12·34
30	13·71	..	10·97	12·34	14·17	10·97	12·34	14·63	12·80
31	..	..	..	11·88	14·63	11·42	..	..	..

TABLE 5.—HEIGHTS of WATER on the BAR at BILBAO, 1873–1874–1875 in FEET (*continued*).

Date.	July.			August.			September.		
	1873.	1874.	1875.	1873.	1874.	1875.	1873.	1874.	1875.
1	11·88	14·63	13·26	11·88	14·17	13·71	12·34	13·71	15·54
2	11·88	14·17	13·71	11·88	13·71	14·17	12·34	12·80	15·08
3	11·42	13·71	14·63	11·88	13·26	14·17	12·80	..	14·63
4	11·42	13·26	..	11·88	13·26	13·71	13·26	..	14·17
5	..	12·80	13·71	..	12·80	13·71	13·71	10·97	13·71
6	..	12·80	13·71	..	..	13·26	13·71	11·42	13·26
7	..	12·34	13·26	12·80	..	12·34	14·63	11·88	12·34
8	12·80	12·34	12·34	13·71	10·97	11·88	14·63	12·34	11·88
9	13·26	..	11·88	14·63	11·88	11·88	14·63	12·80	11·88
10	13·71	12·80	11·88	14·63	12·34	11·42	14·63	13·26	11·88
11	14·17	13·26	..	14·63	..	11·42	13·26	..	..
12	14·17	13·71	..	14·17	..	11·88	..	..	12·80
13	14·17	14·17	..	13·71	12·80	12·34	..	..	13·71
14	13·71	14·63	11·88	13·26	12·80	12·34	..	13·26	13·71
15	12·80	14·17	12·34	12·80	..	12·34	..	13·26	15·54
16	..	13·71	..	12·34	12·34	13·26	..	13·26	16·00
17	12·34	13·26	..	11·88	11·88	13·71	..	12·57	16·00
18	12·34	12·80	12·80	..	..	14·17	..	11·88	16·00
19	12·34	12·34	12·80	..	11·42	14·17	..	..	15·08
20	..	12·34	12·34	..	10·97	14·17	..	..	14·63
21	12·80	11·88	11·88	..	10·97	13·71	..	..	14·17
22	13·26	11·88	11·88	..	10·97	13·26	..	..	13·26
23	13·71	11·88	11·88	..	10·97	12·80	14·63	..	12·80
24	13·71	11·88	11·42	..	11·42	11·42	14·63	13·71	12·80
25	13·71	11·88	11·88	..	12·34	11·42	14·63	14·17	13·26
26	13·71	12·34	11·88	..	12·80	11·42	14·63	15·08	13·71
27	13·26	13·26	11·88	12·34	13·26	..	14·17	15·54	..
28	12·80	..	12·34	11·88	13·71	..	13·26	15·54	..
29	12·80	..	12·80	..	..	..	12·80	15·54	..
30	12·34	..	13·26	..	..	14·17	11·88	15·08	..
31	11·88	14·63	..	..	..	15·08	..	..	..

TABLE 5.—HEIGHTS of WATER on the BAR at BILBAO 1873–1874–1875 in FEET (*continued*).

Date.	October.			November.			December.		
	1873.	1874.	1875.	1873.	1874.	1875.	1873.	1874.	1875.
1	11·88	..	15·54	13·71	12·80	15·54	..	..	14·63
2	11·88	..	15·54	..	12·80	15·08	..	..	14·17
3	11·88	..	14·63	..	12·80	13·71	..	..	13·71
4	12·80	..	..	..	13·26	13·26	..	..	13·26
5	13·26	..	..	..	13·71	12·80	..	11·06	..
6	14·17	..	12·80	..	14·17	12·80	..	12·34	..
7	..	..	..	..	..	12·80	..	..	12·80
8	..	12·34	..	..	..	..	..	..	13·26
9	..	..	..	..	14·63	..	..	..	13·71
10	..	..	..	12·80	14·17	..	..	..	14·17
11	..	..	..	12·34	13·71	..	..	..	14·63
12	..	..	..	12·34	..	..	..	..	15·54
13	..	..	..	12·34	..	..	..	..	15·54
14	..	13·71	..	11·88	..	16·46	..	..	15·54
15	..	13·48	..	11·88	..	..	..	..	15·08
16	11·88	13·26	..	..	..	15·54	..	..	14·63
17	11·88	..	17·37	..	..	15·08	..	..	14·17
18	12·34	11·88	..	..	..	..	..	..	13·26
19	12·80	..	..	..	..	..	..	..	12·80
20	13·26	..	14·63	..	..	..	..	13·26	..
21	13·71	..	13·71	..	..	12·80	..	..	..
22	..	..	13·26	..	13·71	12·80	..	..	..
23	..	..	..	..	14·17	13·26	..	..	..
24	..	15·08	..	..	15·08	13·71	..	12·80	..
25	..	14·86	14·17	..	15·08	14·17	..	..	..
26	..	16·46	14·63	..	14·17	14·63	..	..	..
27	..	16·00	15·08	..	..	..	..	..	..
28	..	15·54	15·54	..	..	..	..	..	13·71
29	11·88	14·63	16·46	..	..	15·54	..	..	13·71
30	11·88	..	16·46	..	..	15·08	..	..	12·80
31	12·80	12·80	16·00	..	..	..	..	..	12·34

MEMOIRS OF DECEASED MEMBERS.

MR. THOMAS WILLIAM DE BUTTS ARMSTRONG, late Chief Engineer and Secretary to the Government of the Central Provinces, India, second son of the late Rev. William C. Armstrong, M.A., of Moydow Rectory, County Longford, Ireland, was born in 1826, and having received a liberal education was at the age of fourteen sent to the college for Civil Engineers at Putney, where he remained about four years. Leaving it in August 1844 he obtained employment under Sir John Macneill, M. Inst. C.E., as assistant engineer on the Dublin and Cashel railway (now the Great Southern and Western Railway of Ireland), and afterwards in Sir J. Macneill's office, and on the Carlow railways. In 1845–6, during the railway mania, Mr. Armstrong, while still in the same service, was, in addition to other duties, much employed in giving evidence before Parliamentary committees in London. From the spring of 1846, for the space of about fifteen months, he served on railway works under the late Sir John Rennie, Past-President Inst. C.E., and under the Messrs. Leahy, of Cork. Mr. Armstrong was next employed on Government works in Ireland under the Commissioners of Public Works, and was for five years resident engineer under Mr. Frederic Barry, M. Inst. C.E., on several important navigation and arterial drainage works in the county of Mayo. These works were varied and important, and in their execution Mr. Armstrong displayed great energy and talent. He was at the same time endowed with genial and high social qualities, which rendered him deservedly popular. He, moreover, managed to combine business and pleasure, especially with regard to field sports, which conduced to his good health and spirits, and subsequently stood him and his companions in good stead on more than one occasion when he was a member of the Darien expedition. During the five years in which Mr. Armstrong was engaged on these navigation and arterial drainage works, he fully established his reputation as a Civil Engineer, and in 1853, when these works were drawing to a close, he accepted an appointment under the late Mr. Lionel Gisborne, and proceeded to Sweden to assist in getting up the surveys, designs, plans, and estimates for the south

Swedish railways between Malmö and Jonköping, which have since been carried out by the Swedish Government.

Before this work was completed Mr. Armstrong was selected by Mr. Gisborne as a member of his staff of engineers, for the purpose of surveying that part of the Isthmus of Darien between Port Escoces and Caledonia Bay on the Atlantic side and the Gulf of San Miguel on the Pacific, with a view to connect the Atlantic and Pacific oceans by a ship canal. Mr. Armstrong left England on the 17th of December 1853, and formed part of the expedition sent to the Pacific side of the Isthmus, under the immediate direction of Mr. H. C. Forde, M. Inst. C.E. Mr. Gisborne and Lieutenant St. John, R.E., made their way on foot from the Atlantic to the Pacific, after much difficulty, and subsequently Mr. Gisborne, accompanied by Mr. Armstrong, endeavoured to return by the same route, but on account of the absence of canoes, and the hostility of the Indians, they were compelled to abandon their endeavours in that direction. From Caledonia Bay, as a base of operations, Mr. Armstrong, in charge of a surveying party, finally made as careful a survey as circumstances admitted, between the Atlantic and the Chuqunaque river, and also took instrumental levellings between these points, thereby connecting the levels previously taken between the Pacific and the River Chuqunaque. He thus completed the survey of a section from sea to sea across a country previously and subsequently closed to all strangers. The result of Mr. Armstrong's levelling showed that the lowest summit level of the Cordilleras, that could then be found, was an elevation of about 1,000 feet above the sea—an impracticable obstacle to the cutting of a ship canal.

In 1855 Mr. Armstrong received an appointment in the Honourable East India Company's service, on the recommendation of Mr. Gisborne, in conjunction with about fifteen others. This was the first batch of Civil Engineers sent to India in the Government service, and they formed the nucleus of the Department of Public Works in that country. Mr. Armstrong's services in India extended over a period of twenty-two years. He rapidly rose in rank, and was distinguished for the ability with which he conducted the important works entrusted to his care, and the tact and kindness he displayed to all with whom he came in contact. On his arrival in Calcutta he was appointed an Executive Engineer, and attached to the survey of the Great Trunk line of road through Orissa. In 1858 he was made superintendent of the Nuddea rivers which comprise the main lines of water communication between the River Ganges and Calcutta, an appointment

held for many previous years by a military officer of high standing and great ability. Mr. Armstrong's services, as superintendent of these most important navigation roadways, were frequently acknowledged both by his then immediate chief, Mr. Leonard, M. Inst. C.E., and by the Government of Bengal. By 1861 he had risen through the four grades of Executive Engineer, and was appointed Superintending Engineer of the Province of Orissa, the province in which he had served as Executive Engineer. He was soon afterwards made Consulting Engineer to Government for the great, but, as they proved, unprofitable irrigation works undertaken by the Orissa Irrigation Company. These duties he conducted with success, till compelled by illness to visit England in 1865. On his return to India in 1867, with restored health, he was appointed Superintending Engineer of the Central Provinces, and soon afterwards became Chief Engineer and Secretary to the Government, which important post he held till his death. His career in these provinces was unusually active and distinguished; indeed, his name is connected with every work of note carried out in them. Among the more important works may be mentioned the trunk roads throughout the country, and the numerous bridges spanning the immense rivers crossed by them: for instance, the Kankan, a stone bridge of twelve arches of 80 feet each, with a roadway 60 feet above the river bed; the Wurdah valley and other state railways, surveyed and constructed for the opening up the coal and cotton districts of these provinces; the exploration and development of the Warora collieries; the large military barracks at Jubbulpur, and the construction of the waterworks for the ancient city of Nágpúr, a work most successfully carried out under the executive charge of Mr. Alexander Binnie, M. Inst. C.E.[1] Mr. Armstrong's services were frequently acknowledged by the Government of India, and on his death, the Chief Commissioner of the Central Provinces testified his appreciation of them by the following official notification in the Government *Gazette*:—

"Memorandum No. 89, dated Nágpúr, the 8th May, 1877.—The Chief Commissioner has received with much regret the intelligence of the death at sea on the 1st instant, of Mr. Armstrong, Chief Engineer. Looking at the important services which Mr. Armstrong, as head of the department in these provinces, has rendered to the Administration, Mr. Morris desires to place on record his sense of the serious loss which the public service has suffered. In the year 1867 Mr. Armstrong joined the Public Works Depart-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 1.

ment of the Central Provinces as Superintending Engineer, and since 1869 he has been Chief Engineer and Secretary to the Chief Commissioner in the Public Works Department. His name is associated with every engineering work of importance—railway, bridge, or road—undertaken in the province during these years; and the success attained in many cases has been largely due to his professional knowledge and experience. Nor can the Chief Commissioner leave unnoticed the great personal interest in his professional work which was a marked characteristic of Mr. Armstrong as Chief Engineer. This laudable eagerness to see more work finished prolonged his stay in the country, and it may thus, it is feared, have been instrumental in shortening his life. All officers associated with Mr. Armstrong in the service must feel with the Chief Commissioner that by his death the Government has lost a most efficient and zealous officer—one whose loss, when announced to the Supreme Government, brought immediately the following telegraphic reply:—'Government of India regret exceedingly to hear of the death of so meritorious a public servant as Mr. Armstrong was.'"

Mr. Armstrong not only conducted his professional duties so as to gain the approval and confidence of his superiors, but also the esteem and affection of his large staff, both military and civil; and it is a pleasing circumstance to have to record that the officers and subordinates comprising his staff spontaneously, on receiving the sad news of his death, subscribed a large sum of money, with a view of perpetuating his memory in the Central Provinces, by erecting some public monument to his name, which is about to assume the form of a stained-glass window in Nágpúr Church. His long residence in India had for the last few years of his life been gradually impairing his health; but the great interest he took in his works, and his anxious desire to see them satisfactorily completed, so that the service should not materially suffer by his absence, induced him to remain a little too long in the country. At the urgent recommendation of his medical adviser he at length availed himself of three months' privileged leave; and he left Bombay in the Peninsular and Oriental steamer *Travancore* at the end of April 1877, for a trip to Australia and back, during unusually hot weather. On the 1st of May following he died suddenly from heat apoplexy off the Malabar coast, in his fifty-first year, having nearly earned his retirement and a substantial pension. The following extract from the Chief Commissioner's minute on the Annual Progress Report of the Central Provinces for 1876–7 is a further proof of how Mr. Armstrong's professional

services were appreciated:—"In conclusion, I cannot omit the opportunity of again recording the heavy loss the department has sustained during the year by the death of Mr. Armstrong. He identified himself with the progress and success of every important work being carried out under his orders; his high professional attainments qualified him at all times to render practical assistance in difficulties to the executive officers who served under him as Chief Engineer. During his long career in these provinces the Government of India has on many occasions communicated its appreciation of Mr. Armstrong's excellent services; and I feel that his death has deprived the Administration of a most devoted and efficient public servant."

Mr. Armstrong was elected a member of the Institution of Civil Engineers on the 10th of April, 1866.

MR. ARROTT BROWNING, second son of the Rev. David Cunningham Browning, M.A., chaplain to the gaol Newcastle-on-Tyne, was born on the 5th of July, 1838, at Newcastle, and was educated there at Percy Street Academy, then conducted by the Rev. John Collingwood Bruce, LL.D. In 1854 Mr. Arrott Browning was under the Marquis of Bute's mining and surveying Engineer at Cardiff, where he had the opportunity of studying the construction of the Cardiff docks and also the mines in that neighbourhood. But he may be said to have commenced his professional career in 1855, as a pupil of Mr. John Plews, M. Inst. C.E., then engaged on the construction of the Northumberland Dock on the Tyne. On the expiry of his articles in 1857, he studied for one year in the Applied Sciences Department of King's College, London, where he was chief prizeman of the year. Early in 1859 he became an assistant to Mr. J. F. Tone, M. Inst. C.E., by whom he was employed successively in superintending the works of the Blyth and Tyne railway, on the preliminary studies for the Border Union, the Border Counties, the Wansbeck railways, the Consett waterworks, and on the Cambo and Rothbury railway. In January 1862 he was appointed as District Engineer on the Contractor's staff for the Mauritius railways. On the completion of the railway, four years after, he returned to England, and again assisted Mr. Tone in parliamentary work; and subsequently he spent some time in Spain surveying mineral railways and other works in connection with the mining industry of the northern provinces.

In February 1867, Mr. Browning entered the service of the Madras Irrigation and Canal Company as an Assistant Executive Engineer. In a few months he was made an Executive Engineer, and was placed in charge of the Hindry Division, which included the construction of retaining walls, the Soonkêsala Anicut, and the Hindry Aqueduct. On the completion of this portion of the canal he was transferred to the Khoondair Division, where he had charge of twelve locks, nine bridges, and other works; to this were subsequently added the Nundial division and the Yalloor subdivision, bringing up the length of canal under his superintendence to 52 miles, and comprising the Nundial Aqueduct, the Jutoor Anicut, six locks, and various bridges and culverts. In 1871 Mr. Browning was made Acting Chief Engineer in India, and in that capacity had entire charge of the Company's operations for more than a year.

In September 1872 he resigned his appointment in India to take up the question of railways in Natal, and proceeded there in November for the purpose of making surveys for the proposed railways. He returned to England in October 1873, having surveyed more than 360 miles of line. On the 15th of June, 1875, Mr. Browning left England again for Natal, the Government of that colony having entered into a provisional contract with Messrs. Wythes and Jackson for the construction of 104 miles of railway. This contract was based on the surveys made by Mr. Browning, which speaks well of the confidence the contractors had in his work. Mr. Browning now undertook the sole control of carrying out this contract for Messrs. Wythes and Jackson in Natal, and to the organizing and carrying out of the same he devoted the remainder of his life, and left it only when his last illness compelled him to do so. He left the Cape on the 20th of March for England, and on the 5th of April, 1877, he died at sea.

Mr. Browning was elected a Member of the Institution on the 14th of January, 1875. He had the entire confidence of his employers, and gained the respect and esteem of all who knew him. He was firm but kind to those who were placed under him, who as well as his employers deeply feel the loss of so experienced and valuable a man at the early age of thirty-eight years.

Mr. CHARLES BENJAMIN LE MESURIER was the second son of Benjamin Le Mesurier, and grandson of Henry Le Mesurier,

hereditary Governor of Alderney. He was born in Guernsey on the 20th day of December, 1829; died of cholera, at Howrah, Calcutta, on the 30th day of November, 1877. He served his apprenticeship in London, with Mr. Richard Boxall Grantham, M. Inst. C.E., and, on the completion of his articles in 1853, was for a short time on the Alderney Harbour works; he then became assistant to Messrs. Walker, Burgess and Cooper, under the late Mr. Garrett at the Commercial Docks, Rotherhithe, and when Mr. Garrett went to the Crimea in the Army Works Corps, Mr. Le Mesurier took charge and finished the works. After this he was employed in the office of Messrs. Walker, Burgess and Cooper, where he remained until the autumn of 1856, when he joined the staff of the East Indian Railway as an Assistant Engineer. He landed in Calcutta in November of that year, and was at once appointed to the Agra district, where the works of construction were then commencing. In May 1857, just before the outbreak of the mutiny, he went for a short time to Cawnpore, to visit his friends on the railway staff in the vicinity of that place. When it became necessary for the European residents to take refuge in the so-called entrenched camp at Cawnpore Mr. Le Mesurier, not wishing to overstay his leave, started for Agra in spite of the earnest entreaties of the large party of engineers with whom he had been spending his holiday. He succeeded in reaching his post after a difficult and dangerous journey; every one of the party of engineers, whose guest he had been, fell in the fight or subsequent massacre at Cawnpore—not one of them escaped. Railway operations were for a time suspended, and during the troublous period which ensued Mr. Le Mesurier, together with the other railway engineers who were so fortunate as to reach Agra, assisted to garrison the fort, or took the field from time to time as volunteer cavalry. On one occasion a party of volunteers, of whom he was one, was cut off by the mutineers, and they were obliged to remain for several days in the fortified dwelling of a native landholder. They eventually succeeded in returning to Agra. As the districts became more peaceable work was gradually resumed, and Mr. Le Mesurier was stationed at Toondla as Assistant to the District Engineer, Mr. Hamilton Lee Smith, M. Inst. C.E. From that time to the day of his death he was engaged continuously upon the East Indian Railway, with but very short intervals of leave of absence for a few weeks at a time. As Resident and District Engineer he has held charge, at one time or other, of almost every division of that railway. He was stationed for a long time at Mirzapore, then at Allahabad, subsequently he had

charge of what is known as the Chord line, and his last move was to Howrah.

During his professional career Mr. Le Mesurier was always an exceedingly active and energetic Engineer, intimately acquainted with every detail of work, prompt to act, and fertile in resource. He was always a good organiser and a capital master of men, from whom he secured good and willing service. His warm-hearted goodness made him thoroughly loved and esteemed by all who knew him. His open-hearted generosity to those in trouble was known throughout the length and breadth of India, where Ben Le Mesurier will long be remembered as a thorough good specimen of an Engineer, a sportsman, an Englishman, and a friend. He was buried at Hourak. The E.I.R. volunteers, in which corps he held for many years a captain's commission, attended the funeral and furnished a firing party. In reporting his death to the East India Railway Board, Mr. Bradford Leslie wrote:—

"By his sudden death the company have lost the services of an Engineer who has served them well, and with unremitting zeal, during a period of over twenty-one years. His death will be regretted by the whole of the company's staff and the Government officials connected with the railway."

Mr. Le Mesurier was elected a Member of the Institution on the 7th of December, 1875.

MR. WILLIAM BEARDMORE was born at Greenwich on the 6th of May, 1824. On leaving school he was apprenticed to his father, Mr. Joseph Beardmore, who was then and for many years afterwards Chief Engineer at the General Steam Navigation Company's works, Deptford. When his pupilage was over, William Beardmore was appointed Assistant Superintendent of the same works, and held the post for about ten years, during which time his ingenuity and inventive talents were constantly being exercised for the benefit of the Company. In 1850 considerable attention was drawn to the necessity of smoke-consuming apparatus for river steamers, and he devised a hollow cast-iron furnace bar, which completely achieved the desired end. Among several patents taken out at this time by Mr. Beardmore, either alone or in conjunction with his future partner, Mr. Rigby, the most important were a superheating apparatus, composed of a box of tubes placed in the uptake of the boiler (No. 2,838, December 10, 1858), and an arrangement for applying high-pressure steam through the medium

of a high-pressure cylinder, working within a low-pressure cylinder in such a manner that the high-pressure steam, having actuated the piston in the central cylinder, passed thence into the external cylinder, where it worked a ring piston before passing to the condenser (No. 626, March 7, 1860). Mr. Beardmore also gave much attention to the construction of direct-acting engines for screw propulsion, in lieu of the cumbrous and antiquated forms of geared and side-lever engines then in vogue; and he patented, in association with the late Mr. Robert Napier, M. Inst. C.E., a direct-acting engine, which in general plan and idea somewhat resembled the trunk engine of Messrs. John Penn and Sons, and was successfully introduced in several ships fitted out by Messrs. Napier.

In 1861 Mr. Beardmore entered into partnership with Mr. William Rigby, for the purpose of carrying out on a more extensive scale the rolling mill and forge at Parkhead, Glasgow, previously established by Mr. Rigby and the younger Napiers. In addition to the manufacture of all classes of heavy forgings for marine engine work, the firm erected rolling mills for the production of plates for ship and boiler purposes. For several years from the starting of these mills large quantities of armour plates for the home and foreign navies were produced, and these were the only rolled armour plates made in Scotland. Subsequently this class of manufacture became gradually restricted at Parkhead as heavier armaments were adopted; and now the chief seat of the armour plate manufacture is at Sheffield, but they are still produced at Parkhead up to 3 or 4 inches in thickness. On Mr. Rigby's death, in 1863, the conduct of the business devolved upon Mr. Beardmore, until 1871, when he took into partnership his brother Isaac, who for a number of years had been managing the forge department. During the whole of this time Mr. William Beardmore's inventive faculties were actively employed, and he took out patents for steam rams for naval purposes, for puddling and re-heating furnaces, for improved processes for the manufacture of iron and steel, &c. At the same time, by his indefatigable attention to all departments, by his industry, energy, and perseverance, the Parkhead works were gradually improved and extended until they became the largest of their kind in Scotland, and achieved an European reputation.

The illness from which Mr. Beardmore suffered began to tell visibly upon him during the last three months of his life, and about a month before he died he removed to Brighton for change of air. There, however, he grew rapidly worse, and passed away on the 11th of October 1877, in the fifty-fourth year of his age

regretted not only by his professional friends and acquaintances, but by all classes of workmen employed under him.

Mr. Beardmore was a promoter and director of the Glasgow and Coatbridge (North British) railway, a line which has been of much service to the district through which it passes; and also of the Glasgow, Hamilton, Coatbridge, and Bothwell railway, which was only opened for mineral traffic a few days after his death. He was elected an Associate of the Institution on the 6th of March, 1860, and was also a member of the Iron and Steel Institute, in the proceedings of which he took much interest.

Mr. WILLIAM JAMES CADETT, son of Dr. James Cadett, was a native of the West Indies, having been born at Port of Spain, Trinidad, on the 15th of July, 1847. At an early age he was sent to England to receive his education. He returned to the West Indies to arrange some private affairs consequent upon the death of his father, and afterwards again set out for England, to qualify himself for the profession of a Civil Engineer. Having arranged, in the first place, to get a sound training in the mechanical branch of the profession, he was articled to Mr. Edward Hayes, Watling Works, Stony Stratford, with whom he remained rather more than two years, and left with the reputation of being a fair workman. Mr. Cadett then matriculated in the department of Applied Sciences at King's College, London, where he remained nine terms, until July 1871, during which time he gained two workshop prizes, one in the Arts of Construction, the other in Geometrical Drawing; and, on completing his studies, was elected an Associate of the College. Mr. Cadett was next for one year an assistant on the staff of Captain L. Flower, River Lee Conservancy, and subsequently became permanently attached to the office, where he gained considerable experience in sanitary matters in connection with the water supply of London, and with the several processes for sewage utilisation. In conjunction with Mr. Edward Dudley, Mr. Cadett gained several prizes for the best designs for various proposed undertakings; almost his last work was in one of these competitions, viz., for the best method of draining the town of Sevenoaks, in which he and Mr. Dudley succeeded in gaining the second prize. Early in the year 1876 he commenced practice in London, which promised, had he lived, to become both remunerative and of considerable extent. Mr. Cadett died,

after ten days' illness, from blood poisoning, on the 22nd of October, 1876, having only been elected an Associate of the Institution in the month of February in the same year.

MR. ARDASEER CURSETJEE was born at Bombay on the 6th of October, 1808. He was a scion of the Lougee family, heads of the Parsee caste in India, and who for more than a century honourably served the East India Company as officials in the Bombay Dockyard. Continuing the traditions of his family young Ardaseer at the age of fourteen entered the Government, service as an assistant to his uncle, Mr. Nourojee Jamsetjee, who at the time was master builder in the dockyard. Having served in the department for six years, and qualified himself as a naval architect, he was in 1828 placed in charge of the shipbuilding yard at Mazagon, where he designed and superintended the construction of several fine vessels. While holding this office Mr. Ardaseer Cursetjee became imbued with an ardent desire to thoroughly master the theory and practice of steam engineering. With the high intelligence and acumen characteristic of his countrymen, he at once appreciated the immense benefits that would accrue to India from the general application of this means of developing its resources, and he resolved to further its introduction by every means in his power. As the best means of attaining this object he in the first place obtained permission from the Government to place himself with Capt. McGillvary, the Chief Engineer of the Bombay Mint, under whom he remained some time, though still retaining his appointment at Mazagon. He soon furnished a proof of his progress by producing a small steam engine and boiler of about 1 HP., made entirely by his own hands, and said to have been the first constructed in Bombay. This engine was set to work pumping water on Mr. Ardaseer Cursetjee's premises, where it continued many years, but it was principally intended as a means of conveying instruction, and its author sedulously invited the natives to study its action, which he took every pains to make clear. In October 1833 Mr. Ardaseer was made "Assistant Builder" at Mazagon, the office being expressly established for him, on the recommendation of the Superintendent of Marine, Capt. Crawford, who had been much pleased with the manner in which he performed his duties and his endeavours to popularise amongst his countrymen the scientific progress of the west. Pursuing his favourite idea he

induced his father to procure from England a 10 HP. marine engine, which arrived in Bombay in parts, and was completed and fitted by the son, without the assistance of any European, to a vessel called the "Indus," also specially built under his directions at his father's expense. Thenceforward the marine steam engine became the principal study of Mr. Ardaseer Cursetjee's life, and he began a long course of experiment and observation which culminated six years after in his being chosen from among numerous European competitors for the important post of Chief Engineer and Inspector of Machinery at the newly established Bombay Steam Factory. In 1835 he introduced gas lighting into Bombay by constructing, at his own expense, gas apparatus for lighting up his own house and garden, which he exhibited gratuitously to the public, who came many hundred miles on purpose to witness this, to them, novel triumph of scientific ingenuity. In carrying out this enterprise he had many disadvantages to contend with; there was no foundry for getting the work properly executed, so that he had to procure all sorts of tools and plant for making the tubes, cocks, &c. Notwithstanding these difficulties the apparatus was pronounced by competent judges to have been as complete as if constructed at any proper factory in England.

At the period when education was beginning to spread in Bombay, and professors of different branches were sent from England to encourage the natives in acquiring knowledge, Mr. Orlebar, Professor of Mathematics at Elphinstone College, cognizant of his anxiety to improve his countrymen, as well as of his acquaintance with practical mechanics, applied to the Bombay Government to allow Mr. Ardaseer Cursetjee to assist him in instructing the natives, especially in mechanical and chemical science, for which permission was gladly accorded. At the same time the rapid increase of steam navigation in Bombay had led to great difficulty in insuring the prompt repair of the engines of the numerous steamers. Towards obviating this state of things Mr. Ardaseer Cursetjee obtained permission from the Government to proceed to England for a year to make himself acquainted with the principal and latest improvements in marine engineering, with a view of afterwards imparting to his countrymen the knowledge so obtained. Arrangements had been completed for his passage on board the 74-gun ship, "Imaum" (afterwards H.M.S. "Liverpool"), which had been constructed at Bombay by the Sultan of Muscat under Mr. Ardaseer's superintendence, and was about to make her first voyage to England as a present from His Highness to the Queen. But sudden illness prevented this, and it was not until a

year after, on the 12th of September, 1839, that he actually started from Bombay. Though the visit of a native of India to this country is no longer remarkable, it was in those days a matter of considerable interest. The enlightened and patriotic motives which prompted Ardaseer Cursetjee to break through the trammels of a rigid caste, and perhaps incur the reproach of slighting the traditions of his countrymen, was thoroughly appreciated; and had he so willed it his sojourn in England might have attained to a continued ovation. But his object was to study the marine engine, and this purpose he steadily kept in view. He was, as a matter of course, presented to the Queen and the Prince Consort; but beyond this he resisted all attempts at lionising, and with the approval of the India Office made an arrangement to work in Messrs. Seaward's engineering shops at Limehouse, where also he took a house. The diary[1] of his life in England during this year (1840), and from which these particulars are extracted, is a most interesting record of the impressions made by western civilization on a highly-educated native of India. His mind was eminently receptive; nothing seems to have escaped his notice, and his comments and criticisms on what he saw evince considerable acumen. It was during this year that Mr. Ardaseer Cursetjee became connected with the Institute of Civil Engineers, having been elected an Associate on the 24th of March, 1840. He had previously been introduced to Mr. James Walker, the then President, and was also a regular attendant at the meetings with his friend Mr. S. Seaward. On one of these occasions he gave expression to his views on the relative advantages of long and short connecting rods for marine engines,[2] and subsequently illustrated them by an elaborate drawing which he presented to the society. He seems to have attached much importance to the privileges thus enjoyed; and as it happened considerable attention was at that time being drawn to the capabilities of auxiliary steam power for ships and the introduction of the screw propeller. In July 1840 he became a candidate for the newly established office of Chief Engineer and Inspector of Machinery at the Bombay Steam Factory, and backed by the powerful testimonials of the most eminent marine engineers of the day, as also of the personal interest of Mr. Walker, he was unani-

[1] "Diary of an Overland Journey from Bombay to England, and of a Year's Residence in Great Britain." By Ardaseer Cursetjee, C.E., F.S.A., Chief Engineer and Inspector of Machinery at the East India Company's Steam Factory and Foundry at Bombay. Tract 8vo. London, 1840.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 68.

mously elected to the office. He returned to India in November, and about the 1st of May, 1841, took charge of the steam branch of the Navy, aided by one chief assistant, four European foremen, a staff of one hundred European engineers and boiler makers, and about two hundred native artificers. He was the first native of India who had been placed over Europeans, and no doubt his path was not one of roses for a long time; but his natural kindness soon made him a favourite with all those placed under him, as he meted out justice to all irrespective of colour or creed. In 1843 the steam factory was opened for carrying out repairs, of which he took charge. The strength of the service was augmented both with ships and men; consequently his work increased to a corresponding extent. In 1851 he was struck with paralysis, and his life despaired of; but he recovered and came to England, and was allowed by the then Court of Directors to visit various cities to see the different improvements in machinery, his great hobby being to introduce novelties into Bombay. At this time he visited America and selected various wood-cutting machines, which were sent to Bombay. He was also the first to introduce the sewing machine, and show its working; and was foremost in introducing photography and electro-plating into Bombay. He returned to Bombay in 1852, and carried on the duties of his office until 1857, when failing health again overtook him.

In July 1858 he retired on a special allowance of Rs.400 a month, being two-thirds of the salary attached to the office, and much higher than the ordinary pension. After coming to England he so far recovered that he entered the service of the Indus Flotilla Company as their superintending engineer. He proceeded to Kotree in Scinde, the headquarters of the company, and took charge of the steam branch and workshops; but in less than two years he was compelled by ill-health to give up the post, and settled down at Richmond, for the remainder of his life, esteemed for his benevolent actions by a large circle of friends both European and Indian. He died on the 16th of November, 1877.

MR. SAMUEL HOCKING was born under the shadow of Carn-Brea Hill, near Redruth, in Cornwall, on the 6th of February, 1807. He was one of a large family, and his father, being a miner, took his son Samuel, at a very early age, to work in the copper mines of Illogan. In these mines, especially in the cele-

brated Dolcoath mine, young Hocking worked for some years, and being employed to turn a ventilating machine, his attention was drawn to its mechanical construction, and much of his leisure was devoted to the construction of a model of a ventilator, in which several improvements were introduced upon the machine he had moved underground. Mr. Hocking ever traced his success in life to the encouragement given by his mother to his mechanical tendencies, and to the efforts she made to cultivate in her son Samuel a love of knowledge. The steadiness exhibited by young Hocking, and the eagerness he displayed in endeavours to make himself acquainted with the principles of mechanics, attracted the attention of one of the largest adventurers in Dolcoath mine, Mr. John Rule, who was about to proceed to Mexico, in charge of large quantities of machinery for the silver mines of that country. Samuel Hocking accompanied Mr. Rule; and there became acquainted with Colonel Colquhoun, R.E. After spending a few years in Mexico, he returned to England, and Mr. Rule placed him, in 1828, with the well-known engineer Woolf, with whom he was a great favourite, and under whom he speedily gained considerable knowledge of the principles involved in the use of steam power. Next, he was employed in the fitting shops of the Hayle foundry, and had charge of the first works at the Clifton suspension bridge, somewhere between the years 1836 and 1843. That scheme failed, and the chains were bought by the company formed for erecting the Hungerford suspension bridge; and Mr. Hocking, as agent for the Hayle Copper-house Company, superintended the work across the Thames. On the 7th of March, 1844, he was elected an Associate of the Institution, and frequently attended the meetings during his residence in London. He also superintended the erection of pumping engines at Old Ford, at Brentford, at Battersea, and at the Croydon Waterworks; and put up the pumping engine at Leek, in Staffordshire, and other places, for the Hoyle Cooper-house Company. When the Company was dissolved, the services of Mr. Samuel Hocking were secured by the well-known manufacturers of safety-fuze, Messrs. Bickford, Smith, and Davey, for whom he reconstructed and greatly improved the machinery in the works at Tuckingmill, in Cornwall, by which the firm were enabled to meet the growing requirements of their trade. He also designed and superintended the erecting of all the machinery in the manufactories established by this firm in Lancashire, in France, in Prussia, in Spain, and in America.

In the midst of his labours, constructing some new machines for the Tuckingmill works, and when apparently enjoying his usual

health of body and vigour of mind, Mr. Hocking was seized with apoplexy from which he never rallied, dying at Rosewarne, Camborne, on Friday, the 16th of February, 1877. Though of a quiet, retiring, and modest disposition, one could not fail to be impressed with his earnestness and enthusiasm, nor to notice evidences of great thoughtfulness about all matters that were allowed to occupy his mind.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Equilibrium of Pulverulent Bodies. By PROF. J. BOUSSINESQ.[1]

(Mémoires couronnés et Mémoires des Savants étrangers, publiés par l'Académie royale des Sciences de Belgique, vol. xl., p. 1–180.)

Pulverulent bodies, such as sand or earth recently turned up, whose particles in sliding on one another experience no resistance except that arising from their mutual friction, are susceptible of many distinct modes of equilibrium.

The only one which has hitherto been studied is the limiting case when the mass is on the point of motion, and when the friction of the particles attains its maximum. Formulæ relating to this state were obtained as early as 1856 by Rankine, and subsequently by Levy and others.

But there is another kind of equilibrium equally important to consider, viz., that which is produced in the interior of a pulverulent mass confined by a wall sufficiently firm to prevent any disturbance of the particles. In this state the friction of the various strata on each other is generally less than in the other; just as, in a solid body in elastic equilibrium, the strains remain always less than those which would produce permanent alteration of its structure: the particles are then retained in position by their mutual actions less forcibly than if the wall were to give under their pressure, and they exercise upon it a thrust greater than the formulæ of Rankine and Levy give. This is the kind of equilibrium studied in the memoir. It is called "elastic equilibrium" because the pressures induced depend on certain small deformations, which the mass, supposed at first homogeneous and without weight, would undergo if it became, as it really is, heavy.

The bodies in question occupy a position midway between solids and fluids; for whilst solids and fluids, submitted to pressures varying from zero to considerable intensities, oppose to any given deformation a constant force—finite for the first, zero for the second—pulverulent bodies resist change of form with an energy so much the greater as the mean pressure to which they are subjected is

[1] "Essai théorique sur l'équilibre des massifs pulvérulents, comparé à celui de massifs solides et sur la poussée des terres sans cohésion," par M. J. Boussinesq, professeur à la faculté des sciences de Lille. Brussels, 1876.

greater; fluids almost when not compressed, they become rigid like solids under pressure. Their co-efficient of rigidity (*co-efficient d'élasticité de glissement*—Lamé's μ), instead of being constant, as in the case of solids, or zero, as in the case of fluids, appears to be proportional to the mean pressure p to which they are exposed. The Author deduces this from the expressions which represent in isotropic bodies the mean of the principal elastic forces (*i.e.* the mean pressure p with its sign changed), and the differences of these forces, in terms of the three principal deformations, δ_1, δ_2, δ_3. Retaining in all the results the terms of two dimensions in δ_1, δ_2, δ_3, and expressing that the matter under consideration ceases, for finite values of δ_1, δ_2, δ_3, to be subject to the action of tangential elastic forces when p is zero, he finds that the normal and tangential components, N_1, N_2, N_3, T_1, T_2, T_3 (according to Lamé's notation), of the pressure, per unit of area, on three elementary planes perpendicular to the axes, have the values (provided they do not exceed certain limits)

$$N_1 = -p\left(1 - 2m\frac{du}{dx}\right),\ T_1 = pm\left(\frac{dv}{dz} + \frac{dw}{dy}\right),\ \&c.,$$

where m is a constant positive co-efficient of considerable magnitude, and where u, v, w designate the molecular displacements parallel to the axes of x, y, z. The same analysis proves that the cubic expansion (dilatation) may be neglected in comparison with the three linear expansions to whose algebraic sum it is sensibly equal, or that the condition of incompressibility $\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0$ holds. The remaining three equations between the N's and T's necessary for determining u, v, w, and p are

$$\frac{dN_1}{dx} + \frac{dT_3}{dy} + \frac{dT_2}{dz} + \rho X = 0,$$
$$\frac{dT_3}{dx} + \frac{dN_2}{dy} + \frac{dT_1}{dz} + \rho Y = 0,$$
$$\frac{dT_2}{dx} + \frac{dT_1}{dy} + \frac{dN_3}{dz} + \rho Z = 0,$$

where ρ is the density of the mass, and X, Y, Z the components of gravity parallel to the axes.

The special conditions existing at the bounding surfaces are as follows:—

1st. At free surfaces, the effective pressure on the outside layer is zero; for the atmospheric pressure around each grain does not influence the mutual action between it and contiguous grains.

2nd. At fixed boundaries (such as the posterior faces of retaining walls), which are sufficiently rough—as they generally are—to prevent motion in the particles adjacent to them, u, v, and w vanish; and in the case of a surface infinitely smooth, the normal

component of the displacement and the tangential components of the pressures are zero.

The integrations of the equations are easy when the mass—of indefinite extent in all other directions—is limited above by a plane making an angle ω with the horizon. The states of equilibrium of a pulverulent mass bounded in this way are infinite in number, and belong to one of two series, according to the values given to two of the arbitrary constants, c, c', introduced in the integration.

Any system of parallel material straight lines, situated in a vertical plane perpendicular to that of the upper slope, changes, through the small deformations it undergoes, into a family of concentric conic sections, similar and similarly situated, the axes of which bisect the four angles which are formed by a vertical straight line and the line of intersection of the upper surface of the mass with the plane aforesaid. These conic sections become circles of very large radius for straight lines parallel to the slope, and are reduced to parallel straight lines when one of the arbitrary constants $c = 0$.

There are, in particular, two systems of equidistant and parallel straight lines, originally at right angles and inclined, the one to the vertical, and the other to the horizontal, at an angle ϵ, which after deformation of the mass remain straight, parallel, and unchanged in length, but are turned with respect to one another through a small angle $\frac{\sin \omega}{m \cos (\omega - 2\epsilon)}$. The squares which they originally formed by their intersections become diamonds, and the ultimate form of the mass may be arrived at by supposing it originally divided into indefinitely thin layers, inclined at an angle ϵ to the vertical, which slide in their respective planes in such a manner, that if one be considered as fixed, any other situated at a distance D in front of it will be displaced downwards by a quantity $\frac{D \sin \omega}{m \cos (\omega - 2\epsilon)}$. The case in which $c = 0$ comprises an infinite number of modes of equilibrium, since there still remains the arbitary constant c', is the most interesting, as it is the only one in which, by properly determining c', the conditions existing at a boundary, whether smooth or rough, are found to hold throughout the extent of any plane cutting the upper slope in a horizontal straight line, in other words, inclined to the vertical at the angle ϵ; and it is the only one in which the particles in this plane remain immovable during the deformation of the mass. Hence equilibrium will still subsist, if the material on one side of the plane be replaced by a retaining wall having this plane for its posterior face. This is naturally the mode of equilibrium produced where such a wall really exists, and it will be the same for two directions of the wall at right angles to each other.

When, therefore, the posterior face of a retaining wall is rough, and inclined to the vertical at an angle ϵ, the settlement of the mass takes place by displacement parallel to the face, and is, as

already stated, equal, for any particle, to the product of its distance from the face by the constant factor $\frac{\sin \omega}{m \cos (\omega - 2\epsilon)}$.

Admitting the existence of the special condition set forth above at the surface of the wall, the pressure R on an unit of area at a depth L (measuring along the face), and the angle ϕ_1 which its line of action makes with the prolongation of the normal thereto, toward the interior of the wall, are given by

$$R = K \rho g L \qquad \tan \phi_1 = \frac{\sin \omega}{\cos (\omega - 2\epsilon)},$$

where $K = \frac{\cos (\omega - \epsilon) \sin \omega}{\cos 2 (\omega - \epsilon) \sin \phi_1}$.

If, on the contrary, the wall were mathematically smooth, the values of $\tan \phi_1$ and K would be 0 and $\frac{\sin \epsilon}{\tan (\epsilon - \omega)}$.

The total pressure P on an unit of width of the wall is $\frac{1}{2} K \rho g L^2$ (where K has one of the values given above), and the point of application of its resultant, whose direction is parallel to R's, is at a depth $\frac{2}{3}$ L (L being in this case the total height of the wall measured along the face, $= \frac{h}{\cos \epsilon}$).

In obtaining these results the limit of elasticity of the matter has not been taken into consideration. Now, just as in solving the problem of the equilibrium of a perfectly elastic solid, under the action of given forces, it is necessary to express that the greatest deformation at any point must be less than that which will cause a permanent set, so it is necessary, in this case, to express that the greatest linear extension at different points of the mass must not exceed that limit which it cannot surpass without danger of disruption (*éboulement*).

Pulverulent bodies, being without cohesion, are incapable of transmitting tensions, whence it follows, by the analysis, that the greatest linear extension δ_1, must be less than the ratio $\frac{1}{2m}$. The limit of elasticity, being thus less than $\frac{1}{2m}$, can always be expressed in the form $\frac{\sin \phi}{2m}$, where ϕ denotes an angle (lying between 0 and $\frac{\pi}{2}$ generally), whose value for each particular kind of matter must be determined by experience. This angle may be called the angle of internal friction of the mass.

It therefore appears that the only states of equilibrium possible are those in which the condition $p > 0$ and $\delta_1 > \frac{\sin \phi}{2m}$, expressing the imperfect elasticity of the matter, are satisfied.

A first consequence of the imposition of these new conditions is to make the constant c vanish, *i.e.* to reduce all the possible

modes of equilibrium of an indefinite mass to those which can subsist in a mass bounded by a plane wall, and further such modes of equilibrium, which then depend on a single parameter ϵ, say, are shown to be possible only when $\cos^2(\omega - 2\epsilon) \gtrless \frac{\sin^2\omega}{\sin^2\phi}$.

Their number, unlimited so long as the inclination of the upper slope to the horizon is zero, becomes more and more restricted as that inclination becomes greater, and when $\omega = \phi$ they are reduced to one only; when ω exceeds ϕ equilibrium becomes impossible. Thus the theory explains the impossibility of a pulverulent mass existing with a slope whose inclination exceeds the angle of friction of the matter of which it is composed.

The formulæ already obtained depend on special conditions, and relate to the case of a mass, originally without weight and free from pressure, which, on becoming heavy, takes a new state of equilibrium without the layer next the retaining wall having moved, if the wall be rough, or having moved out of its own plane, if it be smooth. Practically, however, in forming such a mass against a rough immovable wall already built, the particles contiguous to the wall only remain stationary so long as they are but slightly compressed. But the addition of successive quantities of earth or sand subjects them to increasing pressure, and causes them to move through finite distances, the result being an entirely different state of equilibrium. This state is that in which the internal stability of the mass is greatest, or in which the maximum extension δ_1 has at each point its least value compatible with the degree of resistance of the wall. The analysis shows that δ_1 attains its minimum value $\pm \frac{\sin\omega}{2m}$ when $\epsilon = \frac{\omega}{2}$. This, then, is the value of ϵ which corresponds to the most stable state of internal equilibrium.

If, however, the wall is not sufficiently firm to allow of the mass attaining its maximum stability, the state of equilibrium produced is that in which the whole resistance of the wall is utilised. In these cases the value of the parameter δ, which defines the mode of equilibrium, is determined by the relation

$$\tan 2\epsilon = \frac{\cos 2\epsilon_1 \cos 2(\omega - \epsilon) - \cos 2\omega \cos 2(\epsilon_1 - \epsilon)}{\sin 2\epsilon_1 \cos 2(\omega - \epsilon) - \sin 2\omega \cos 2(\epsilon_1 - \epsilon)}.$$

Whether the stability of the mass attain its maximum or not, the direction and intensity of the resultant pressure on a wall inclined at an angle ϵ_1 to the vertical are given by $P = \frac{1}{2} K \rho g L^2$,

where
$$K = \frac{\sin\omega \cos(\omega - \epsilon_1) \cos 2(\epsilon_1 - \epsilon)}{\cos 2(\omega - \epsilon) \sin\phi_1}$$

$$\tan\left(\phi_1 + \epsilon_1 - \epsilon + \frac{\pi}{4}\right) = \frac{\tan\left(\epsilon_1 - \epsilon + \frac{\pi}{4}\right)}{\tan^2\left(\frac{\pi}{4} - \omega + \epsilon\right)},$$

by substituting for ϵ its proper value.

All these modes of equilibrium are stable; for the wall may be supposed without weight, but held in position by an externally applied force, and by the pressure of the mass which it supports. If then the wall were to move towards or from the mass, the pressure of the latter upon it would increase or diminish, and this would exceed or be exceeded by the external force, so that the wall would tend to return to its original position.

Hence it is not necessary to make the thickness of a retaining wall greater than will enable it to support a pressure slightly exceeding that which corresponds to the least stable state of equilibrium.

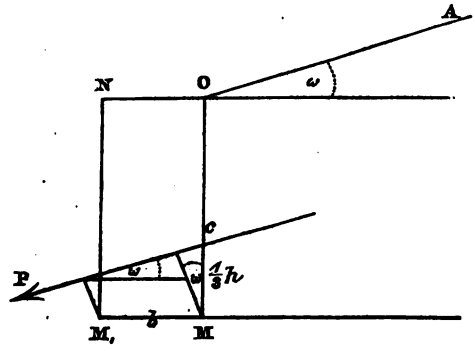
Assuming the posterior face of the wall to be vertical (in which case the direction of the resultant pressure will be parallel to the upper slope), and ϕ to be = 45°, the following table gives the greatest and least numerical values of K for different values of ω.

TABLE I.

	ω = 0°, ± 10°, ± 20°, ± 30°, ± 40°, ± 45°
Greatest {value of K}	·1716, ·1765, ·1935, ·2320, ·3404, ·7071
Least {value of K}	1, ·9848, ·9397, ·8660, ·7660, ·7071

The equilibrium of such a mass will therefore be stable provided the wall can support a pressure, applied at one-third of its height, parallel to the upper slope, and slightly greater than $\frac{1}{2}$ K ρ g L^2, where K has the values ·1716, &c.; but in order that the most stable state of equilibrium may be realised, the values of K must be taken from the lower line in the table.

For example, the retaining wall M O N M_1, whose faces M O, M_1 N are vertical, would tend to turn about the front edge M_1.



In order to determine the condition of equilibrium it is necessary to equate the moment of the weight of the wall about M_1 to the moment of the pressure of the mass (P) about the same axis.

Calling ρ' the density of the wall, b its breadth, and h its height, the weight of an unit of length will be expressed by $\rho' g h b$, and its moment about M_1 by $\frac{1}{2} \rho' g b^2 h$. The point of application of the pressure P will be c, at one-third the height of the wall, and the direction of its line of action parallel to the upper slope, its moment about M_1 is therefore

$$\tfrac{1}{2} \rho g h^2 K (\tfrac{1}{3} h \cos \omega - b \sin \omega).$$

By equating these expressions, and reducing, the value of the ratio $\frac{b}{h}$ is found to be

$$= \frac{2}{3} \times \frac{1}{\tan \omega + \sqrt{\tan^2 \omega + \frac{4}{3} \frac{\rho'}{\rho} \frac{1}{K \cos \omega}}},$$

1. Suppose the thickness of the wall is to be just sufficient to insure equilibrium, and assume for ρ' the value $\frac{3}{2} \rho$, which will not in general be far from the truth, then, substituting for K its numerical value from the upper line of Table I., the following results are obtained

for ω =	0°	10°	20°	30°	40°	45°
$\frac{b}{h}$ (minimum stability) =	·1953	·1866	·1802	·1761	·1786	·2060

2. If, on the contrary, b is to be such that the most stable mode of equilibrium may subsist, the value of K must be taken from the lower line in the table, and

for ω =	0°	10°	20°	30°	40°	45°
$\frac{b}{h}$ (maximum stability) =	·4714	·4107	·3486	·2887	·2325	·2060

A consideration of these figures proves that the practical rule of making the thickness of a retaining wall equal to one-third of its height insures in general sufficient stability.

The Author then proceeds to examine the condition of the mass when disruption commences, and deduces the equations relative thereto. He also obtains in polar co-ordinates the equations applicable to the limiting state of equilibrium of a mass, plastic or pulverulent, submitted to pressures very great in comparison with its weight.

M. L.

On the Limes and Cements of Casale, Piedmont, and Liguria.

By G. SIGNORILE.

(Giornale del Genio civile, vol. xv., pp. 301–317.)

In the year 1846 the Author was instructed by the Italian Government to examine the limestones of Casale, Piedmont, and Liguria, with reference to their use on railways.

In 1850 the making of forty millions of bricks for the lining of the Giovi tunnel, led to further experiments on the calcining of the materials for the artificial mortar with pit coal, instead of with wood, which had been employed in the first instance. It resulted that lime which was excellent when calcined with wood, deliquesced if calcined with coal containing pyrites. The Author is now desirous to review the labours of thirty years, and to republish his earlier discoveries, bringing down the account so as to comprise those of the latest date.

The methods of investigation employed have been direct experiment, and chemical analysis. In order to avoid the numerous anomalies which occur in the action of hydraulic materials, certain precautions are indispensable. Perfect calcination has to be obtained in kilns of the ordinary structure, heated with wood, and fed from above. The tempering of the lime should be effected with the least quantity of water required to produce a stiff argillaceous consistency, similar to that required for making bricks when tempered. The lime should be kept under water, the temperature of which should vary between 51° and 70° Fahr.; a necessary precaution in the case of experiments, some of which last for six and others for twelve months or more.

The first sample of the immersed lime was tested by Vicat's needle; and the progressive hardening of the mortar was ascertained by means of the percussive apparatus designed by the same analyst. The durability of mortars composed of lime and sand was tested by forming them into small bricks, which were exposed to the atmosphere for periods, varying from six months to several years; the samples being always kept in a somewhat damp situation. The resistance offered to compression by these samples was measured by an ordinary machine for applying pressure by the attachment of weights to a lever, up to the point of crushing. Some of these experiments were made six months after the lime was burned; some after one, two, and even three years.

The general results of the experiments, the details of which are presented in a tabular form, are as follows:—

The limes of Casale, of Montferrat, and of Superga (near Turin) occupy the first rank among true hydraulic limes, and are but little inferior to the best French limes investigated by Vicat.

Next come the limestones of Liguria, belonging to the brown Eocene calcareous beds. These are followed by those of the

dolomitic rocks, which contain a certain proportion of clay. Finally come the imperfectly hydraulic limes of Tortona and Godiasco, which abound in the valley of the Borbera, under the mountains of Antola. All the above rocks, with the exception of the Superga, belong to the Eocene series, a formation which prevails in Emilia, Tuscany, and the Roman provinces. Throughout this system occur good materials for hydraulic mortars and cements. In the neighbourhood of Superga, limestone is found in the form of pebbles, or small boulders, in conglomerates of the middle tertiary or miocene epoch.

The difference in chemical constitution of the limestones in the same stratum is insisted on by the Author. Stone from the same quarry is generally regarded as of one quality, while the difference due to a few feet of vertical height in the layers from which the sample is taken may be very great. Thus at Casale there is a range of from 1 to 4 millimètres in the grade of hydraulic value of the lime; and the same is the case both at Superga and in Liguria. In the brown Eocene rocks an enormous difference occurs between the hydraulic value of successive strata, so that limes of excellent, of limited, and of extremely low value are intermixed, without evincing by any exterior characteristic the respective nature of each layer.

Another difficulty is the small increase of bulk of these limes when slaked. The slaking is troublesome, as the limes in question commence to soften before removal from the furnace, at certain temperatures, and in this state only continue to change very slowly, so as often to effloresce after use in building.

As to the chemical analysis of limestone, the Author states that the method in present use is, to determine the insoluble residuum left, when the specimen is treated with boiling chloridic acid. This method, though easy of application, is not unlikely to prove misleading, owing to the facts that the residuum may contain extraneous matter, and that the particular molecular state of the silex, when in the well, which is a matter of much importance, cannot thus be ascertained.

The Author enters minutely into the theory of efflorescence in magnesian limestone cements. Proofs are cited as to the remarkable durability of the artificial cement before described, as used in railway works in the valley of the Scrivia in 1848. The Paper concludes with the declaration that magnesian lime, without the presence of either clay or silex, can never be truly hydraulic; and that while the best natural hydraulic cements never exceed a cohesive value indicated by 4·4 to 5 millimètres by the method of Vicat, artificial cements, with the mixture of a proper proportion of clay, obtain a value indicated by a resistance of 2·2 millimètres.

F. R. C.

Graphic Diagrams for the Strength of Teak Beams.

By GUILDFORD L. MOLESWORTH, M. Inst. C.E.

(Professional Papers on Indian Engineering, 2nd series, vol. vi., pp. 407–412, 5 diagrams.)

Mr. E. H. Stone, in his tables and diagrams "for facilitating the calculation of teak beams," employed separate diagrams for each span, and these diagrams involved curved lines. Mr. Molesworth has simplified the formulæ by expressing them in terms of the ratio of the depth to the span; and thus one diagram suffices for all spans. Further, by making the scale for spans proportional to the square of the span, and not as the span simply, the curves in the diagrams are replaced by straight lines. Scales are added for other timber besides teak.

The diagrams are constructed for transverse strength, for stiffness, and for weight; and for beams of two scantlings, in which the breadth is equal to half the depth, and to two-thirds of the depth. The formulæ employed to determine the working load, are—

For transverse strength, $L = S^2 \times T \cdot K_T$ . . . (1)

For stiffness, $L = S^2 \times E \cdot K_E$ . . . (2)

For weight of beam, $W = S^3 \times k \cdot w$ . . . (3)

L = safe load in lbs. distributed;

W = weight, in lbs., of a beam of which the length is equal to the span;

S = clear span, in feet;

T = modulus of rupture; being the breaking weight applied at the centre of a beam 12 inches long and 1 inch square, supported at both ends;

E = modulus of elasticity; or that load which, if applied to the centre of a beam 12 inches long and 1 inch square, supported at both ends, will produce a deflection of 1 inch;

K_T = co-efficient of transverse strength $= 0{\cdot}1 \left(\frac{12}{N}\right)^3$, when the breadth is half the depth; or, $0{\cdot}1333 \left(\frac{12}{N}\right)^3$ when the breadth is two-thirds of the depth;

K_E = co-efficient of stiffness $= 0{\cdot}02 \left(\frac{12}{N}\right)^4$, when the breadth is half the depth; or, $0{\cdot}02667 \left(\frac{12}{N}\right)^4$ when the breadth is two-thirds of the depth;

N = number of times the depth is contained in the span;

k = co-efficient of weight, varying with the depth of the beam;

w = weight, in lbs., of a cubic foot of timber.

The diagrams of transverse strength and stiffness are to be used to determine the depth of the beam; the diagram which gives the lowest load being followed. Stiffness is calculated on the assumption that the deflection should not exceed $\frac{1}{10}$ inch per foot of span. The diagram for weight is intended to show how much the load is increased by the weight of the beam itself. The diagrams are accompanied by four tables, containing values of the modulus of rupture, of the modulus of elasticity, the products of their moduli with the co-efficients of transverse strength and of stiffness, and the weight of timber of different kinds.

D. K. C.

Proportions of Eye-bar Heads and Pins, as determined by Experiment. By C. SHALER SMITH.

(Transactions of the American Society of Civil Engineers, vol. vi., pp. 263–268.)

In experimenting on this subject during the years extending from 1857 to 1866 the Author ascertained as an "absolute, unchangeable fact," (1) that a pin the diameter of which was two-thirds of the width of the bar was the least size which would develop the full strength of the bar; (2) that the required sectional area across the eye, for any given width of bar, increased with the diameter of the pin; (3) that the best shape of the eye-bar head depended upon the material and mode of manufacture; "weldless" eyes being circular in outline, and "hammered" eyes Gothic, or, in other words, having 50 per cent. greater sectional area behind the pin than on either side of it.

The Author directs attention to the fact that the diameter of pins in some instances will be governed by the bending stress, and sums up his general conclusions in a table shewing diameter of pin, &c., expressed in terms of the width of bar, as follows:—

Width of Bar.	Diameter of Pin.	No. 1. Hammered Eyes.		No. 2. Weldless Eyes.	
		Metal Section across the Eye.	Maximum Thickness of Bar.	Metal Section across the Eye.	Maximum Thickness of Bar.
1·00	0·67	1·33	0·21	1·50	0·21
1·00	0·75	1·33	0·25	1·50	0·25
1·00	1·00	1·50	0·38	1·50	0·38
1·00	1·25	1·50	0·54	1·60	0·54
1·00	1·33	..	..	1·70	0·59
1·00	1·50	1·67	0·70	1·85	0·70
1·00	1·75	1·67	0·88	2·00	0·88
1·00	1·75	1·67	0·88	2·00	0·88
1·00	2·00	1·75	1·08	2·25	1·08

Examples.—If a bar 4 inches by 1 inch be attached to a 3-inch pin, the sectional area across the eye (table, under "No. 2, Weldless Eyes") should be $4 \times 1 \cdot 5 = 6$ square inches if weldless, and $4 \times 1 \cdot 33 = 5 \cdot 33$ inches if hammered, and the maximum thickness of bar which could be used without imposing too great a bending stress upon the pin would be $4 \times \cdot 25 = 1$ inch. The sectional area behind the pin would be 3 square inches in the first instance, and $2 \cdot 66 \times 1 \cdot 50 = 4$ square inches in the other, as previously explained.[1]

B. B.

Pneumatic Caisson Foundations of the Prague-Smichow Bridge.

By J. REITER.

(Mittheilungen des Architekten- und Ingenieur-Vereines im Königreiche Böhmen, vol. xi., pp. 7–9, 13–16, vol. xii., pp. 20–24.)

Before describing the above-bridge foundations, the Author gives a short outline of the history of pneumatic pier foundations, and enumerates some of the principal instances where the method has been applied. He then describes successively, the staging for the erecting and sinking of the caisson of the Prague-Smichow bridge, the caisson itself, the sinking apparatus, and the practical results obtained.

The staging was composed of two double rows of piles, running parallel with the line of the river and embracing between them the space in which the caisson was to be sunk. The inclosure of the site of the pier was completed by a few transverse piles, at the down-stream end at right angles to the longitudinal rows, and at the up-stream end, in the form of a wedge. All these piles were strongly connected by ties, stays, and braces. A platform was established at about 8 feet above mean water-level and extended over the whole area of the staging, but the central part, within the inner piles, was made removable. Here the caisson was put together and, when ready, suspended to the staging by ten strong screws with chain attachments. After slightly lifting it, to allow the clearing of the removable portion of floor underneath, it was let down into the river. The bearings of the screws were supported by the inner piles, which were of greater height than the outer ones, inclined struts joining their ends and serving to stiffen the whole structure. There was besides at the top level a travelling crane, two narrow longitudinal platforms, and on one side, at one

[1] Compare with Mr. Berkley's results (Proc. Inst. C.E., vol. xxx.). The proportions recommended and adopted by him after many experiments were: Diameter of pin, 0·75; metal section across the eye, 1·25; metal section behind the pin, 1·00. Thus the 4-inch by 1-inch bar would have a 3-inch diameter pin, and a sectional area of 5 square inches across, and 4 square inches behind the eye.—B. B.

end, a small overhanging platform where another crane unloaded the material from boats alongside the staging.

The Author states that the cost of the staging amounted to £4 8*s*. per square mètre, or 8*s*. 2*d*. per square foot of area covered by the caisson. A comparison between numerous stagings of this kind led him to conclude that this is a fair mode of expressing the cost, and that, as a rule, it varies between £4 and £6 per square mètre, or 7*s*. 4*d*. and 11*s*. per square foot of caisson area.

The caisson was entirely made of wrought iron, and had in plan the shape of a rectangle, to which were added, against the short sides, a semicircle and an ogive. Its clear width was 22 feet, and its total length 64 feet.

A series of transverse girders, 3 feet 4 inches apart and 2 feet high, formed the floor upon which the masonry of the pier rested. Against their bottom flanges were fixed the plates of the ceiling of the caisson chamber, there being for the latter a clear height of 7 feet 2½ inches above the cutting edge of the caisson. There was therefore a fair margin allowed to make up for the amount of which the caisson edge penetrated the ground below the level in the chamber, without interfering with the excavation. The floor girders were fixed on to the sides of the caisson, and also supported on triangular brackets projecting from these sides. Before commencing the sinking, the spaces between the brackets were lined with masonry. The transverse stiffness, due to the flooring, was increased by an arched plate rib in the centre of the chamber, and by four horizontal cross stays. The shafts, two in number, had an elliptic cross section (diameter 5 feet 3 inches and 3 feet 4 inches), and their vertical axis was made to coincide with the centre of gravity of each half of the chamber, so as to reduce to a minimum the transport of soil inside. These shafts could be lengthened according to the depth to which the caisson had to be sunk. This was also the case with the prolongation of the external plating of the caisson above the floor, formed of a series of horizontal rings. In the present instance there were four such horizontal rings, each 3 feet 5 inches high and $\frac{3}{16}$ inch thick.

The total weight of wrought iron in one caisson amounted to 52½ tons. The comparison of the weights of ten similar caissons has led the Author to conclude that the weight of such caissons may be accurately expressed in function of the area covered by them; it amounts, with very little variance, to 450 kilogrammes per square mètre, or 92 lbs. per square foot. In the Prague-Smichow bridge the weight was 445 kilogrammes per square mètre.

The erection and caulking of the caisson on the staging took about twenty-one days. After having been slowly let down into the river, its weight with that of the masonry lining caused it to sink some 10½ inches into the coarse sand of the river bed. The spaces between the floor girders were then filled with concrete, and the shafts lengthened. The air-locks were fixed on the top

of the latter and put in communication with the blowing machine. This was placed, with the accompanying engines and boilers, on barges moored to the staging.

It had been proposed to extend the foundations to a depth of 19 feet 8 inches below ordinary mean water-level; but on account of a depression in the strata underneath the bed of the river, the sinking had to be carried down to a depth of 30 feet 2 inches. When 18 feet 9 inches were reached—which had required the additional weight of four courses of granite facing, each 1 foot 7½ inches high, filled internally with rubble masonry—the work had to be stopped to lengthen the air shafts. During this operation, the compressed air escaping from the caisson chamber, a further sinking of 10 inches took place. Upon introducing again compressed air, the caisson rose, and it was found that when the internal pressure in the chamber exceeded by 7½ lbs. per square inch the atmospheric pressure, the caisson could be maintained in suspension. This observation gave an easy means to determine approximately the amount of friction developed along the sides of the caisson; for the total weight in the caisson was balanced by the upward pressure of the air in the chamber added to the friction in the ground. The total weight, including all masonry and ironwork, was 916 tons; the pressure exerted by the compressed air, taken at 7½ lbs. per square inch, 638 tons; the difference, 278 tons, represents the part of the load taken up by the friction. This friction was developed in a layer of 13 feet thickness, composed of 9 feet 9 inches of sand and 3 feet 3 inches of coarse gravel irregularly stratified. The surface of the caisson bearing against the ground was 183·2 square mètres; therefore the friction per square mètre was 1·5 ton, or about 2·8 cwt per square foot.

This figure agrees very well with those obtained by Gerber and Bolzano in their experiments during the construction of the foundations of the Simbach and Lech bridges. They had to deal with a stratum of gravel, and found the friction there to vary between 1·6 ton and 1·8 ton per square mètre, or 3 cwt. and 3·35 cwt. per square foot.

Two plates accompany this Paper, and fully show the details of the caisson and its staging.

A. O. B.

Bridge over the Danube to connect the Buda and Pesth Railways.

By J. SEEFEHLNER.

(Zeitschrift des Arch.-u Ing. Vereines Hannover, vol. xxiii., cols. 29–50, 3 pl.)

This bridge was necessitated by the continually increasing importance of the Hungarian capital. A project was accordingly prepared in the Public Works Department, which comprised the

extension of the existing station at Steinbruch on the Pesth side of the river, and its connection with the Franz-stadt station and the station at Uj-Buda, also branch lines to the pig farm at Steinbruch, the public slaughter-house and cattle market, the Pesth Custom House, the goods station, and the new terminus in Pesth; at the site selected the breadth of the river at low water is 1,150 feet.

By the terms of the specification, the masonry was to be of "Neustift" stone, a hard and very compact limestone. For coursed rubble work, the area of the face of any stone was not to be less than $1\frac{3}{4}$ square foot, and in ashlar work the stones had to be at least 1 foot thick. As regards cast iron, its ultimate resistance to crushing was to be 45·75 tons per square inch, and in the case of wrought and rolled iron 22 tons. The main girders were required to bear a tensile strain of $4\frac{1}{2}$ tons; the cross and longitudinal girders 4 tons per square inch; and all parts of cast steel a strain of 10 tons per square inch.

The tenders of MM. Filleul-Brohy having been accepted, the work was commenced in August 1873. The foundations of the river and land piers were laid in caissons, those for the latter being rectangular, while the former had semicircular ends. The various parts of the caisson were brought riveted to the yard, the plates being bent and punched, so that only the fitting together was done at the site of the bridge.

A scaffolding or staging was built over the site of the land piers; on this was laid a platform to support the winches which lowered the caissons. The staging piles were driven by a 4-HP. steam rammer; the weight of ram was 24 cwt., and the fall about 20 feet. The cost of driving was about 1*s.* a yard, through a soil consisting of coarse sand and rubble. The construction and setting-up of the caissons took twenty-seven to thirty days on an average, and their aggregate weight for all the bridge piers was, in round numbers, 38 tons. The caissons for the foundation of the river piers were sunk by the plenum or compressed air process in the usual way, but there were special mechanical contrivances for emptying and filling the buckets which expedited the work considerably. The capacity of the buckets was 1·35 cubic foot, and they could be filled and emptied eleven times in ten minutes, so that the average daily excavation amounted to 32·7 cubic yards. While the preparation of the foundations was in progress, a heavy flood occurred which destroyed the staging, and filled the caissons with water. This was pumped out, at the rate of 68 tons per hour, by Letestu's steam pumps, the peculiarity of which consists in the form of the piston.

The materials and workmen were taken from the building-yard to the piers in large boats towed by a 4-HP. steamer, and the material was lifted out of the boats by steam cranes and winches of improved design. The steam cranes (Chrétien's patent) were capable of lifting 4 tons, and consumed about 5 cwt. of coal daily.

The hand crane by the same patentee had a lifting power of 3 tons. The steam winch (Mégy's patent) was the most efficient and economical of all the hoisting appliances. Full details of this and all the other machines employed are given by the Author in the plates which accompany the Paper.

The statical computations were made for two continuous braced girders with parallel straight booms, compression and tension bars, and two footways each 6½ feet wide. The clear width of each opening is 308·3 feet, the effective width 321·4 feet, and the depth of the girder one-tenth of this latter dimension. The computations are made under the assumption that the loads on the bridge per lineal foot was 1·38 ton (4·56 ton per lineal mètre) for fixed loads, and 1·58 ton (5·21 tons per lineal mètre) for moving loads, and that the moving load may be considered as uniformly distributed; that the cross section of the girder is constant; that the limiting stress may be considered constant, and without regard to the differences of the strains, and to the effective width; and that the fourfold system of the bars could be split up into four single systems. The Author shows at great length the admissibility of these assumptions.

The booms of the main girder were box-shaped, the horizontal plates of which were 4½ feet wide, and attached to bars from 1 foot to 2 feet wide. These plates were made to abut as nearly as possible at the joints, and the stays and angle irons were butted in the middle of each bay. At the joints there were special plates for connecting the tension bars, of which there were four kinds. The compression bars were attached outside the stays, and every pair was connected with some part of the structure by a flat-bar lattice bracing.

The vertical ribs were also connected by a similar lattice bracing, and they served to secure the upper cross stays and cross girders, and to support the footway cantilevers. The cross and longitudinal girders and the wind stays or braces were of the usual construction. The saddles of the free movable supports were of cast iron, and the rockers of cast steel, lead sheeting being laid between the boom and the upper saddle plate, and also between the lower plate and the top of the pier below. All the ironwork was made by Cail and Co., of Paris, the different parts being there riveted together in convenient lengths, and simply fitted at the site of the bridge. Detailed drawings are given of the machines used to test the strength of the materials employed, the results of which are recorded in tables.

The setting-up of the girders was done on a fixed staging, and at first was carried out in short lengths of two or three bays on each side of a pier; but as it was thus difficult to insure the exact connection and position of the lower boom, a modification was made, and the lower booms of No. 3 pier were set out at their full length on the staging; the cross and longitudinal girders fixed between them, and rails laid on the latter, on which travelled

cranes, winches, and wagons, for the lifting up and conveyance of the material; the verticals and struts were then set up in position, and the upper boom attached.

In July 1875 a violent hurricane occurred, which moved the whole girder of the second span (just then completed) more than 3 inches out of position, and the girders of the third span were similarly displaced by a gale in October of the same year. Their restoration to the original positions, work of difficulty and anxiety, was effected by American screw-jacks and winches. The cost of sinking and laying the foundations was about 2*s.* 2*d.* per cubic foot for the shore piers, and from 1*s.* 10*d.* to 2*s.* 1*d.* for the river piers.

The average rates for masonry were as follows:—

	s.	*d.*	
Coursed rubble	0	11	per cubic foot.
Ashlar	1	3	„
Cut stone	4	3	„

From the drawings it appears that the total length of the girders was 1,290 feet, but the leading dimensions have not been given in the paper. The weight of metal in the bridge is over 3,000 tons.

W. H. E.

The St. Louis Bridge over the Mississippi. By M. Lavoinne.

(Annales des Ponts et Chaussées, 5th series, vol. xiv., pp. 5–71, 2 pl.)

The convergence of several railways at St. Louis, and on the opposite bank of the Mississippi, rendered it necessary to erect a bridge over the river to connect them. A company was formed for the purpose, and incorporated by Act of Congress in 1868. Peculiar difficulties had to be encountered in laying the foundations of the bridge, for the sand forming the bed of the river, which is largely deposited in the summer, is liable to be scoured away to a great depth when the river is coated with ice, owing to the contracted undercurrent acquiring a great velocity. The dip of the underlying rock is also very great, being only 13 feet below low-water level on the St. Louis side, whilst on the opposite side it is 108 feet. Under these circumstances it was absolutely necessary to carry the foundations down to the rock, and as it was important to reduce the number of the piers as much as possible, both on account of the costly nature of the foundations and of the shortness of the suitable season for erecting them, being only from the middle of August to the middle of December. The site chosen was a narrow part of the river opposite the centre of the town; and the material selected for the superstructure was cast steel, so that the

spans might be made very large. The bridge was designed to have three spans, and, as it had been found by experiment that cast steel could bear a considerably greater strain in compression than tension, girders of two arched steel tubes, placed one above the other and connected by bracing, were adopted.

The western abutment was commenced in 1868, and the foundations, 13 feet below low water, were laid by means of an ordinary cofferdam. The foundations of the two piers and of the eastern abutment were carried down to the rock by means of caissons sunk by the aid of compressed air, and a hydraulic sand pump was used for removing the sand from the bottom of the caissons. The caissons for the piers were made of plate iron, of a hexagonal form, 82 feet long and 60·7 feet wide, divided into three compartments, each 19·7 feet wide. The working chamber, 9 feet high, was connected with the upper part of the caisson by seven shafts, the air locks having been placed at the lower end of the shafts to avoid removing them each time that a length was added to the caisson, and rendering the working chamber the only part needing to be filled with compressed air. The sinking of the caisson of the east pier to a depth of 102 feet below low water occupied one hundred and thirty-three days, and filling the working chamber with concrete fifty-three days. For the west pier these operations occupied seventy-seven and fifty-three days respectively, the depth being 76 feet. The bottom and sides of the caisson of the eastern abutment were made chiefly of wood instead of iron, with layers of oak beams above the working chamber to a thickness of 5 feet. The caisson was made watertight by a casing at the sides, of plate iron $\frac{3}{8}$ inch thick, and over the top of the working chamber, and projecting 10 inches below the bottom to assist the sinking. There were three shafts, one connected with a double air lock, and the two others with single ones placed at the level of the working chamber. The caisson was sunk to a depth of 108 feet, and only the outer envelope of the working chamber was filled with concrete, the interior being filled with sand. The spans of the arches, measured at the level of the springing of the upper tube, are 520 feet for the centre opening, and 502 feet for the two side openings, with a rise of 59 feet $8\frac{1}{2}$ inches and 56 feet 5 inches respectively. The lower roadway of the bridge for carrying the railway is placed at the level of the top of the underside of the arches, and the carriage roadway is $26\frac{1}{4}$ feet above the railway at the centre of the bridge. The width between the parapets is 54 feet. The tubes are 12 feet apart centre to centre. The distances between the four girders are 12 feet for the centre ones and $16\frac{1}{2}$ feet for the side ones. The piers at the springing of the arches are $32\frac{1}{2}$ feet wide. The steel tubes, forming the top and bottom flanges of the segmental trellis girders, have a mean length of 11 feet 10 inches, and an external diameter of 1 foot 6 inches, and are connected by being grooved into collars joined by bolts. The tubes consist of six segments of laminated steel, varying in thick-

ness from 1⅛ inch to 2½ inches from the centre to the springing, by variations of the internal diameter, and fastened together by a steel casing ¼ inch thick, which butts at its ends against the connecting collar, and is pressed against the segments by bolts. The collars are pierced horizontally by stout steel pins with cylindrical ends projecting beyond the collars, on which wrought-iron bars fit, bracing together the two tubes. These bars vary in width between 1 foot 1 inch and 1 foot 8 inches, and in thickness between 1$\frac{9}{16}$ inch and 2½ inch from the centre to the springing; and, as they are liable to be subjected to both tension and compression, each couple is braced together. The lower roadway, carrying two lines of rails, each line passing between one central and one side girder, is supported by cross girders fastened to bars hanging down from the upper tube where they are below it, and to the upright bars supporting the upper roadway for the rest of the span. The upper roadway is borne on cross girders, which rest on the upright bars fastened to the upper tube. The space between the cross girders is covered with iron plates, ⅜ inch thick, which serve to protect the roadway from sparks from the engines below, and to stiffen the bridge against gales of wind. Wind ties are placed in the portions of the arches below the railway connecting the bottom tube of one girder to the top tube of the adjoining one, and also above the railway between the two central girders. The limit of the safe strain was estimated at 12·7 tons per square inch of section in compression and 8·9 tons in tension.

The erection of scaffolding for putting the girders in place would have been both difficult and costly, on account of the shifting nature of the river bed, the depth of the solid rock, and the amount of protection needed against damage in floods or in the breaking up of the ice. The navigation also would have been impeded; and the progress would have been slow, as only the scaffolding for one span could have been erected at a time. The girders were accordingly erected from the piers and abutments by joining together a quarter of the span length by length, which, fastened to the piers at the springing, could bear its own weight like a bracket. Then by supporting this portion from above by a system of iron bars, carried over a timber tower erected on the pier, and fastened to a similar length on the opposite side, or at the abutments, anchored to the bank, some more lengths of tubes and bracing could be added, and the end of this additional portion supported by bars, passing over a mast raised up on the girder and joined at the opposite end to the springing plate, which enabled the central portion to be added. When the two central girders were in place, the outer ones were put together from scaffolding put out from the central girders. The weight of a girder over the centre opening is 217 tons, of which about two-thirds consists of steel. If iron had been used instead of steel the weight would have been two and a half times greater, and the increase in expense £26,000.

The total cost of the bridge, and of the works for connecting it with the railways on each shore, is as follows:—

	£.	£.
Foundations:—		
Western abutment	61,035	
Western pier	83,468	
Eastern pier	110,337	
Eastern abutment	119,544	
		374,384
Superstructure		388,863
Viaduct and tunnel on right bank		77,995
Viaduct on left bank		48,016
Connecting lines on left bank		85,440
Workshop and its repairs		78,644
Boats, &c.		15,006
Superintendence		48,026
Accidents and damages		47,225
Sundry expenses		181,911
Total		£1,345,510

The total length of the roadway of the bridge proper is 1,300 feet, and that of the approaches 534 feet; together 1,834 feet. The bridge was opened for traffic in July 1874.

L. V. H.

Cable Making for Suspension Bridges, as exemplified at the East River Bridge, New York.

By W. HILDENBRAND.

(Van Nostrand's Engineering Magazine, vol. xvii., pp. 171–184, 193–201, 289–300.)

The method adopted by the Chief Engineer, Col. Roebling, for the cables of the East River Bridge is the same as that used in the case of the Niagara and other suspension bridges, and consists in taking each wire of a cable over the opening by itself, then adjusting its length, and finally combining them all by a wrapping into a cable. This was preferred to that of making a cable of wire ropes, mainly because the strength of a straight wire is 10 per cent. greater than that of a twisted one: hence a wire-rope cable would have been heavier, more costly, and more bulky, exposing a greater surface to wind and atmospheric influences. It was also preferred to the third possible method of using straight wires, but first making up the cable on shore, and then hauling it into position, because this requires a space equal in length to the cable to be available on one or the other side of the bridge (since straight wires cannot be coiled up for transportation), and this, in such a crowded district, was out of the question. In addition, where a cable is made up first and suspended afterwards, the upper strands are strained more than the lower, and thus the distribution of the load cannot be accurately known. The disadvantage of the method adopted is

that it involves much loss of time, as the towers and anchorages must be finished before cable-making can begin.

The general features of the undertaking are first given. The floor of the bridge, 85 feet wide, is to be supported by four cables suspended in three spans—a middle one of 1,595½ feet between the centres of the towers, and two side spans each 930 feet from the centre of the tower to the face of the anchorage. Each cable consists of nineteen strands of three hundred and thirty-two parallel wires, and therefore contains six thousand three hundred and eight wires, having a total ultimate strength of 10,730 tons. Each strand is attached by a 7-inch iron pin to two anchor bars 9 inches by 1½ inch; the wires not passing directly round the pin, but round an intermediate "shoe" of cast iron, which increases the bending diameter to 17 inches. Whilst being made, the strand hangs considerably above its final position (55 feet at the centre of the middle span), and the gap thus left between its end and the anchor bars is occupied by a long cast-iron bar called the "leg." The strand is thus kept clear of the main cable during its making and the regulation of its length; while the tension to which it is subjected (about three-fourths of its full working tension in the finished bridge) tests the quality, takes out waves or bends, and facilitates the wrapping together. The running out of the wires takes place from the Brooklyn anchorage, where the wire rings are received, spliced together, and wound on large wooden drums. An end of this wire is taken off the drum, given a half-turn round a grooved wheel called the "travelling sheave," and then fastened to the leg. This travelling sheave is attached to an endless travelling rope stretched between the two anchorages; and this rope being now set in motion carries forward the sheave and the double length of wire with it to the anchorage at the New York side. On reaching this the wires are transferred from the sheave to the shoe, and their length is regulated in accordance with a "guide-wire," previously suspended, and adjusted to the desired deflection. This regulating is performed by men standing in "cradles," or light platforms, hung by wire ropes at various points along the line of the cable. To communicate between these, and generally all over the work, a light foot-bridge is carried across all three spans. When all the wires of a strand have been adjusted, they are tied together by a wire-rope lashing about every 16 inches, and then lowered to their permanent position. Nineteen of these strands compose the cable. When all have been got into position, the temporary lashings are removed, powerful screw squeezers press the strands into cylindrical shape, and a wrapping of No. 10 wire completes the cable. All large cables previous to these have been made of seven strands only, but here a jump has been made to nineteen; there being no intermediate number which allows of the strands being collected into a truly cylindrical shape.

The various structures and appliances thus seen to be necessary for the carrying out of the work are next described in order. The towers, each containing 40,000 cubic yards of masonry, are built

of granite from Maine. Their dimensions on plan are 140 feet by 59 feet at high water, and 126 feet by 43 feet at the top under the cornice. The summits are 272 feet, and the saddles in which the cables rest 267 feet 6½ inches above high water. These saddles rest each on forty-three iron rollers of 3½ inches diameter, movable on a cast-iron bed-plate 4½ inches thick. The anchorages, built of limestone with granite quoins, are 124 feet by 111 feet at the ground-line and 117 feet by 104 feet at the top; their total height at the face is 89 feet above high water. They are divided by arches running lengthwise into three piers, in which the anchor plates are bedded. The anchor chains, starting vertically upwards from these anchor plates, make a quarter circle over the masonry, so that they emerge horizontally to take the ends of the cables. The links of the chains are composed of flat bars, varying from 9 inches by 3 inches to 7 inches by 3 inches. The connecting pins vary also from 7 to 5 inches in diameter. The shoe is a link-shaped casting with flanges, and, in addition to its use in increasing the bending curve, prevents any lateral slipping of the wires, and forms a point of attachment when the strand is being moved from its temporary to its final position. The leg which, in the temporary position, unites the strand to the anchor chain, is a trough-shaped cast-iron bar about 12 feet long, having a half-round block cast on at one end for the shoe to take hold of. An important point is the fixing of its length. This is best done by actual trial with the guide-wire, but it is generally desirable to have the legs cast before other things are in readiness, and in that case their length must be ascertained by calculation. The mathematical investigation required for this purpose is given in the Paper.

The "traveller" is a ⅜-inch rope of steel wire, forming an endless line between the two anchorages. On the Brooklyn side it takes two turns round a double-grooved driving wheel, 11 feet in diameter, and is connected by bevel gearing and belting with an engine in the yard below; the arrangement of gear being such that the movement of the rope can be stopped, started, and reversed without stopping the engine. The speed at which the rope is worked is about 4·2 feet per second, and it then takes about fourteen minutes to move the distance between the anchorages. Between the anchorages the rope is supported on sheaves placed on the towers and on the cradles. The travelling sheave is a light wooden wheel, 5 feet in diameter, with a grooved rim of zinc, which is secured to the traveller by a hanging goose-neck bar, so as to clear the intermediate sheaves. It is heavily weighted to keep it vertical in high winds. Each traveller carries two of these sheaves, the distance between them being equal to the whole span, so that as one reaches the New York side with its pair of wires the other comes up to the Brooklyn side to receive the next pair. The cradles are five in number, three in the middle and one in each side span, and are light platforms with open iron bottoms and sides of oak, strengthened by iron truss rods. They are supported by four cables of crucible cast-steel wire, three of which are

$2\frac{3}{8}$ inches in diameter, and the fourth, which also carries the foot-bridge, $2\frac{5}{8}$ inches in diameter. At the towers these cables rest on wooden blocks, and at each anchorage are attached to anchor bars of their own by sockets and screw stirrups. The foot-bridge, instead of being suspended from its two cables, as on previous occasions, was laid directly on the cables themselves, thus lying more conveniently for access to the strands, and also giving a stiffer platform and one less liable to damage from wind. It was formed of oak slabs 3 inches by $1\frac{1}{2}$ inch, nailed to longitudinals of the same size, which lie immediately above the cables and are secured to them by screw stirrups.

The erection, which is next described, was rendered very difficult by the height of the bridge above the water (200 feet) and the continual passage of vessels. The first operation was to tow across a scow carrying one of the travelling ropes, which was paid out as it went, and allowed to sink to the bottom. The farther end was then attached to a drum worked by a steam engine, and advantage was taken of a short lull in the passage of vessels to start the engine and wind up the rope, which was done with such speed that in six minutes it had risen out of the water and was clear of all masts. The other half of the traveller was taken across in the same way, and these being joined were then utilised to pull across the second traveller. A "carrier" rope was next brought across after the first method, to help as a support for the heavy foot-bridge and cradle ropes. These were landed at the Brooklyn side, and pulled across by a hemp rope worked from an engine at the New York side. Whilst going across, they were supported about every 50 feet by "hangers," consisting of two overlapping hooks hung from the spindle of a grooved roller which ran along the "carrier." These were removed after the rope was in place. The cradles were next hoisted on their towers, allowed to slide down to their places, and there lashed securely. The foot-bridge floor was then laid, and two light ropes were fixed as handrails, thus rendering it complete.

The next operation was to suspend and adjust the guide-wire, a matter of the utmost importance, as all wires are regulated by it. It must be of such a length that the cables, which at first hang parallel to it, may afterwards, under the influence of the load, sink just so far as to bring the under-side of the bridge at its centre to the level prescribed by law, viz., 135 feet above high water. Now, the forces acting on the cable to influence its curve are as follows:—(1) The load tends to stretch the wires, and so produce a depression; (2) the diagonal stays, by taking some of the load at the parts next the towers, tend to raise the cable there and depress it at the centre; (3) the difference of the horizontal tensions in the middle and side spans causes the saddles to move inwards and the middle span to sink until these tensions are equalised; (4) the cables being manufactured in a vertical plane, are afterwards drawn into an inclined one, and thus tend to rise at the centre; (5) changes in temperature continually cause the

cable to rise and fall. The methods of allowing for each of these, and of adjusting the guide wires accordingly, are described at length. These wires were first carefully selected to be of equal weight throughout, were then suspended, and left there until a perfectly calm day permitted the regulation to take place. When this had been completed throughout, the wires were let free, and were found to be in perfect balance.

The cable itself and the manner of making it are next described. Cables for previous bridges had always been made of charcoal iron wire, No. 9 or No. 10 gauge. For the Cincinnati Bridge they were 12 inches in diameter, and were made up of five thousand two hundred wires, No. 9 gauge, having an aggregate strength of 4,212 tons. Those for the East River Bridge, however, were to have about two and a half times this ultimate strength, and it was therefore resolved to make them of steel. The specification (which was the result of a long series of experiments) stated that the wires were to be of superior steel, hardened, tempered, and galvanised: they were to be of No. 8 gauge full, or to weigh 1 lb. per 14 feet before galvanising: they were to have a breaking strain equivalent to 160,000 lbs. per square inch, an elastic limit of not less than ·47 of this, and a modulus of elasticity between 27,000,000 and 29,000,000 lbs. When unrolled from the ring they were to lie quite straight, with no tendency to coil up; this straightening to be accomplished by winding them at once from the galvanising trough on to a winding drum under high tension, the drum being placed at a considerable distance to allow the wire to cool. Two kinds of tests were specified: (1) a stretching and breaking test, applied to a short piece from every ring, and to a piece 60 feet long from every fortieth ring; (2) a bending test, applied by winding 1 foot of wire from each ring in close coils round a ½-inch rod, which it must stand without breaking.

The contract, on this specification, and with the understanding that the wire was to be crucible cast steel, was awarded to J. Lloyd Haigh, of South Brooklyn, at $8\frac{7}{10}$ cents per lb. The wire supplied by him averaged 172,000 lbs. per square inch breaking strain; and after two strands had been made, it was resolved to thicken the wire to No. 7 gauge (or 11 feet per lb.), which, whilst giving a breaking strain only 2,000 lbs. less, saved one-sixth in the number of wires, and, consequently, in the time of construction. The wire was delivered in coils of 60 to 70 lbs. weight. Each coil received three coats of oil (applied cold) before being used. Successive coils were joined together by small screw couplings, about 1½ inch long, which were found to give about 95 per cent. of the strength of the wire; while the ordinary splice, by tapering the ends and wrapping them round, when laid side by side, with fine wire, though strong enough for iron wire, gave only about 75 per cent. for steel. After being spliced the wires were wound on a wire drum, and were then ready for use. They were taken across in two lengths at a time, as before described, by means of the "travelling sheave." The wires were then made into a strand

by being squeezed together, about every 2 feet, with a powerful tongs, and then tied with four turns of No. 14 galvanised wire: this is done by men descending in a sort of carriage from the towers to the middle. The strand (which is now a solid cable 3½ inches in diameter) is next "let off," *i.e.* shifted from its temporary seat on the "leg" to its permanent connection with the anchor chain. For this operation, which requires the greatest care, the "shoe" which fits on to the leg is grasped firmly by two long bars, bolted to a double steel plate in front, and at the other end carrying a set of four 8-inch sheaves. These form the commencement of a system of chains and pulleys, ending in a hemp rope worked by an engine. By pulling on these the shoe is first drawn back slightly and allowed to rise off its seat on the leg. The engine is then reversed, and the strand allowed to travel slowly forward till it reaches the anchor links, where a pin, passed through the eyes of the latter, receives the shoe. The ropes are then slackened off, and the strand is next lowered from its temporary rollers to its permanent place on the saddle at the tower. For this purpose the strand is grasped at four points close to the rollers by clamps fixed in a bow-shaped frame. This frame is attached to the lower end of a vertical screw, which can be moved up or down through a nut worked by handspikes. The strand being first raised clear of the flanged rollers, these latter are withdrawn, and the strand is then lowered to its place on the saddle. It has then to be regulated. For this, as there must always be small differences in length of strands, the shortest is chosen as guide-strand, and the rest shortened to it by pulling the shoe back from the pin in each case, and inserting a segment of the proper thickness between the two. The adjustment of the side spans so that they shall accurately balance the middle span is difficult, and is done by fixing the position of a particular tangent line (the investigation for which is given), using this as a sight-line, and lowering the cable till it touches this line.

When all the strands have been got into position, the cable has to be wrapped. For this the men are carried along the cable on a light platform suspended from flanged rollers, which run on the cable itself. As they proceed they first force the strands into a circular form by two "squeezers," each consisting of two half-round steel bands, which are slipped over the cable and then drawn together by bolts worked with long wrenches. In the East River Bridge the wrapping is to be twofold; first round the seven inside strands, before the others are made, and then round the whole nineteen. The mode of proceeding is first to take off the temporary lashings for a few feet in advance, then put on the squeezers about 1 foot apart, and tighten these up, first saturating the cable with oil; then to start the wrapping machine. The squeezers are moved one in front of the other alternately, as the wrapping comes up to the hindmost. The wrapping machine consists of a drum carrying the wire, and revolving on an inner sleeve, which itself fits pretty tightly on the cable. On the same

sleeve, close by the drum, revolves a steel-faced ring having two arms, one of which carries a counterweight, and the other a roller. On the steel face is a groove lying in the tangent line, drawn through this roller to the circumference of the cable. The wire (which is No. 10 gauge galvanised) is led from the drum over the roller, and through this groove to the cable. The drum is then turned one way and the ring the other, which has the effect of winding the wire off the drum and on to the cable, the counterweight keeping it all the time under strong tension. The wire as it coils on the cable squeezes itself between the last coil and the sleeve, and so pushes the latter along the cable for just the distance required. As soon as the cable is wrapped it receives several coats of oil paint, and is then ready to take the superstructure. This is put on symmetrically to the towers, and simultaneously in the middle and side spans. After the greater part is attached the holdfasts of the saddles are removed, and the cables thus left free to assume their natural position of balance.

W. R. B.

Viaduct over the Douro.

(Revista de Obras Publicas e Minas, Lisboa, vol vii., pp. 1–34, 57–89, 97–136.)

The memoir presented to the Royal Portuguese Railway Company by MM. Eiffel et Cie., the designers and constructors of the viaduct across the river Douro, in the neighbourhood of Oporto, contains a minute description of the work then proposed to be carried out, and which has since been completed and opened for public traffic. The leading dimensions of the viaduct are, a total length of 1,158 feet from end to end of the abutments, and a height of 201 feet from low-water level to the upper surface of the rails. The central opening is 525 feet wide, and clears the river, which at the point of crossing was found to be deep, and the bottom of such a character as to make it advisable not to construct any piers upon it. An arched form was selected as the most suitable for the purpose, notwithstanding the unusually large span, which called for novel treatment and a special design. It became necessary, in the first place, to abandon the use of any spandril filling, the reasons given in the Paper being that the expansion of the various parts would tend to disturb the equilibrium, and would require a large quantity of metal, otherwise unnecessary, to be used to counteract its effects and insure the stability of the structure.

The plan which suggested itself was to make the arch with sufficient stiffness to resist unaided any uneven distribution of load coming upon it, and this was secured by giving it the form of a crescent, having a depth of 32·81 feet at the crown and tapering gradually down towards the abutments, where it terminates upon

pivots in the usual manner. The ribs of the arch are two in number and have the intrados and the extrados joined together by vertical pieces cross-braced; they are placed 49·21 feet apart from centre to centre at the springing line, and are inclined upwards towards each other, so that the width between them at the top becomes reduced to 12·96 feet; the whole is substantially tied together, by a system of cross-braced framing. The spreading out of the base is for the purpose of enabling the structure to resist the violence of the storms to which it may be exposed.

On either side of the central, or river arch, the viaduct consists of continuous girders supported by piers composed of wrought-iron columns in clusters.[1] On the south side there are two spans of 122·62 feet each between the centres of the bearings, and one of 120·16 feet from the centre of the bearing to the face of the abutment; on the north side there are two spans of 122·62 feet and 120·16 feet respectively. In the original design it was proposed that the longitudinal girders should be carried on the top of the arch, but this was afterwards modified, as it appeared advisable to reduce, as much as possible, the area exposed to the action of the wind. They were therefore lowered and placed so that the level of their upper surface should correspond with the extrados of the arch at the centre; in fact, the central portion of the girders, for a length of 170·21 feet, forms part of the arch. As the remaining distance from this to the piers on either side was too great to span conveniently, a support was placed upon the haunch of the arch to divide it into two equal spans of 94·33 feet. The continuous girders are of the single intersection lattice type, with a uniform depth of 11·48 feet; the total length of those on the south side is 557·34 feet, and on the north 434·72 feet. They are in couples, placed 10·17 feet apart, and carry the permanent way for a single line of railway, by cross girders on the top. The clear width between the parapets is 14·76 feet and the total length of the metallic superstructure 1,163 feet.

The Paper gives the dimensions of the various plates and angle irons employed in the viaduct, and their general arrangement. The weight of the ironwork in the arch is stated to be 504 tons, and of the girders, supports, and permanent way over the arch 223 tons, making the total weight of the central opening 727 tons. The longitudinal girders and superstructure of the remaining portions of the viaduct weigh 26½ cwt. per lineal yard. The rolling load was calculated not to exceed 72 cwt. per yard.

The Paper concludes with an interesting series of tables, nineteen in number, showing the strains to which the arch will be subjected under varying conditions of loads, temperature, and action of wind, the calculations of which can only be properly appreciated by referring to the Paper, where they are given in great detail.

G. Kn.

[1] The piers as actually executed have been made of masonry.

New York and Long Island Bridge.

(Report of Board of Consulting Engineers, New York, 1877.)

On May 1st, 1876, competitive designs were invited for a bridge for road and rail, upwards of 10,000 feet in total length, and including two large spans of 734 feet and 618 feet clear opening, and 135 feet high. In order to place the several designs on the same basis a full specification of the loads, strains, and general conditions accompanied the invitations to tender.

Rolling Load.—For the single line of railway a load of 5,000 lbs. per lineal foot for 15-feet spans and under, decreasing to 3,000 lbs. for a 60-feet span, and to 1,620 lbs. for an 800-feet span. For the roadway 75 lbs. per square foot for ordinary spans, and 50 lbs. for the two large spans.

Wind and Temperature.—A wind pressure of 24 lbs. per square foot acting at right angles to the bridge and upon a train of cars 10 feet high; or a pressure of 40 lbs. per foot upon the unloaded bridge. Changes of temperature to the amount of 150° to be provided for.

Tension Members.—A factor of safety of 3 for dead load, wind and changes of temperature, and of 8 for rolling loads, which for "double-rolled refined iron" is equivalent to a working strain of 8 tons per square inch when the load is wholly dead, 5½ tons when half dead and half rolling, and 3 tons when wholly rolling.

Compression Members.—For wrought-iron square-ended pillars a strain of 8,000 lbs. per square inch up to a length of twenty-four times the least radius of gyration, and above that length the factor of safety to be as for tension members, and the ultimate resistance per square inch to be calculated by the formula

$$P = \frac{40{,}000}{1 + \frac{l^2}{40{,}000\, p^2}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which l is the length and p the least radius of gyration.

Eight sets of plans and estimates were submitted to the consulting engineers. The estimated cost of the 734-feet span ranged from 558,000 to 1,160,000 dollars, and the types of construction included the ordinary truss, hinged arches, suspension cables with stiffening girders, and the cantilever and central girder type sometimes known as the "continuous girder of varying depth." Of these it will be necessary to describe only the three premiated designs.

(1) Messrs. Clarke, Reeves, and Co. submitted a design and tender for the bridge upon the hinged arch system of Captain J. B. Eads, M. Inst. C.E. The arch proper consists of two lenticular struts or girders resting against each other in the centre where

they are hinged, and also hinged at the top of the piers. From the top of the pier to the rock, some hundred feet below, similar struts extend in continuation of the arch form. The main arches, from which the roadway is suspended, are of "Phœnix" or hollow columns of wrought iron 30 inches in diameter, and the lower members of plates and angles. The piers also are composed of "Phœnix" columns, and as they are designed to take only such strains as may come upon them from unequal loading of the arches and a portion of the strain of wind pressure, they are subject to both tensile and compressive strains, and are proposed to be anchored to the foundations. Messrs. Clarke and Co. would erect the arches by building them out panel by panel from the shore, suspending the same by inclined stays fastened to temporary towers at the piers and anchored back. For the single-line bridge the amount of their tender was 1,767,274 dollars, of which sum the 734-feet span constituted 601,910 dollars, and the 618-feet span 437,107 dollars.

(2) The Delaware Bridge Company tendered for the work and submitted a design of considerable merit, in which the main spans were of the cantilever and central girder type. Each cantilever or bracket is divided by two intermediate chords, parallel to the inclined top chord, into three subsidiary brackets superimposed to each other, and 36 feet deep. By thus avoiding the necessity of carrying all the weight to the top of the central tower over the pier, the designer claims that there results great economy in the towers and in the long compression members of the web. In erecting the bridge the two cantilevers would be built out from the piers, and the 200-feet central girder would be built on a wooden truss 300 feet long, counterbalanced and rolled across the space intervening between the ends of the cantilevers. There was little difference between the tenders for this and the preceding design, the total amount being 1,778,315 dollars, of which 561,868 dollars were for the 734-feet span, and 421,550 dollars for the 618-feet span.

(3) Messrs. Henry Flad and Co. furnished a design and estimate for a work somewhat similar in general principles to the last, but the cantilevers in this instance consisted of a number of long straight suspension links extending from the top of the towers to equidistant points along the roadway. Sagging of the links is prevented by a system of circular arc bracings connecting the several parts. No tender was submitted for a single-line bridge, but for a double line the estimated cost was 851,949 dollars for the 734-feet span, and 691,289 dollars for the 618-feet span, amounts about 8 per cent. in excess of the Delaware Company's tender for the same work.

B. B.

On Surveying for Railways in Sumatra. By J. L. CLUYSENAER.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1876–77, pp. 73–86).

The Author considers two methods specially worthy of consideration. The one commences with a study of existing maps, from which a certain direction is chosen and levelled.

With the other method, after a careful examination of the ground, a direction is assumed for the general survey, from which a strip of country can be defined for detail survey.

The former method was followed by the French engineers in prospecting for the line from Constantinople to Adrianople, of which country scarcely any, even the roughest, maps existed. Two observers with aneroids, set out on horseback for Adrianople, the one direct, the other exploring the cross valleys. At distances of 100 yards altitudes were taken, while the standard barometer at Pera was read from hour to hour, and the route was fixed by cross bearings to important points such as mountain-tops, minarets, &c. In this way 25 to 30 miles per day could be accomplished, whilst the altitudes showed a maximum error of 6 feet when compared with subsequent spirit-levelling. On the basis of this survey the direction was chiefly decided upon. After these observers followed a person with an aneroid, who marked out a practicable route by small flags. After him followed a theodolite party; 2 miles behind them a measuring party drove stakes at every 30 yards, sketched the country, the breadth of the roads, streams, &c., and were followed closely by a spirit-leveller, who took cross sections in addition to a longitudinal section. In this way a progress of from 3½ to 6 miles per day was made. From the resulting plan the final direction was determined, and a survey made in the usual way, with repeating circle, level compass, and aneroid, curves having been set out. A measuring party drove stakes at every 10 yards, whilst another took cross sections, and the rear was brought up by a spirit-leveller. The average day's work was from 1,600 to 2,200 yards, and is said to have cost only £32 per mile (500 francs per kilomètre). After describing the methods given by Oppermann,[1] Hoffmann,[2] and Bösch,[3] the Author gives a geographical description of the island of Sumatra, and proceeds to detail the method followed in that island, the object of the survey being to determine the direction of railways and roads for the conveyance of coal from the coalfields of the Padanj Highlands to the West Coast.

Each party consisted of a chief engineer, a second engineer, and

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[1] Oppermann, C. A., "Traité complet des Chemins de Fer économiques." Paris: Dunod, 1873; pp. 12–34.

[2] "Ueber Tracirung von Eisenbahnen in offenem und coupirtem Terrain," by F. Hoffmann, in 'Allgemeine Bauzeitung,' Wien, 1870, p. 59.

[3] L. Bösch, "Topographische Aufnahme für Vorarbeiten in Eisenbahnen," in 'Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover,' 1872.

three assistants, one engineer and two assistants remaining for the general service. The staff was subsequently increased by one party of similar constitution, and by six assistants, giving two to each party. Owing to sickness and various causes there were generally only three or four of these assistants available.

For the preparation of a plan and longitudinal section, the work was divided into: *a*. General reconnaissance. *b*. Rough survey. *c*. Detail survey.

The general reconnaissance was performed by means of aneroid and compass. The former instrument was also used for the altitudes of the general survey, whilst the position of the stations was determined by "tranche-montagne" compass and chain. Each of the three parties was provided with two Richer's tacheometers. As the work progressed, and the surveyors became more practised, two staffholders per instrument were found to be insufficient, and this number had to be increased to six. More are needed in a broken or wooded country than in open plains.

The mean level of the sea was determined by three tide gauges in Troesan Bay, and the result carried over to Solok by a Troughton and Simms level, and from thence on through the Highlands by the tacheometer. A flying survey with the aneroid, chiefly without datum, over an extensive region gave an outline of the country, and pointed out those valleys likely to come into consideration in the laying out of railways. A barometric levelling following closely the line of main watershed indicated the passes by which the country remaining to be surveyed was limited. The "tranche-montagne" compass proved a useful instrument, being very handy, rapidly set up, and giving fairly long sights of 80 to 100 yards. Distances were measured by the chain, and verified by steel tapes.

The general survey was plotted to a scale of 1 to 10,000, and, with the aneroid readings added, was forwarded to the head office and there worked up into a complete whole. On these plans a direction was drawn by the chief of the party, to be afterwards modified by consideration on the spot by the head of the survey. These maps formed the foundation of later detail surveys, and show not only the mountain passes and general direction of the railway, but also the maximum and minimum gradient permitted by the ground.

For a complete survey for a railway from a mountain pass to a valley or plateau, a triangular piece of country must be taken, of which the mountain range is the base and the two sides are the centre lines of two railways, one of which has the maximum and the other the minimum ruling gradient. Within this triangle the best direction for the line must be found. The cost of such a survey confined the Author to the survey of one broad strip of country.

On the maps of the preliminary or general survey no contours are sketched, but for the elucidation of the sketch maps single contours were often drawn. The detail survey was executed

exclusively with the tacheometer, and was plotted to a scale of 1 to 2,000. Principal stations were transferred to the plan by means of co-ordinates, for which purpose the Author recommends ruled "sectional" paper. Whenever two or more tacheometer parties could work in the same direction, the base line was set out and measured in advance by the chief of the party, and the surveyors started at distances apart of 2,000 to 3,000 yards.

The portion between the secondary watershed and Brandewijn Bay presented extraordinary difficulties; it was here impossible to work through any length of base line at once, and as with the utmost zeal it was found that the plans could not be sent in by the required date, two parties were set to work so as to meet. The result was satisfactory, notwithstanding that for two days before meeting the parties could only communicate by a long detour.

In order to afford a check upon the progress of the surveys the bi-monthly reports to head-quarters contained a statement of the latest points observed by the various parties. These points were laid down on a general map provided with contours corresponding to those used by the surveyors.

The survey for the Padanj Highland railway was carried out in a similar manner. In this beautiful and well-cultivated region the open character of the country enabled the survey to proceed very quickly. It was necessary, in consequence of the breadth of the valleys, to extend the width of country included in the flying survey to 3,300 yards, and in some cases even 5,500 yards. Here also the "tranche-montagne" compass was used, together with aneroid and chain. The Author, however, advises the use of the tacheometer even in flying survey, whenever, as in the case of a watershed, a considerable number of points can be observed at one setting up. It is particularly useful in a country under cultivation, where damage would arise from the trailing of the chain.

On this flying survey, plotted to a scale of 1 to 10,000, was based the tacheometer detail survey, which, as in the case of the coal line, was conducted throughout by only two persons per instrument.

The main roads and some bye-roads were surveyed with the tacheometer; this survey was afterwards extended, so that a network of triangles was obtained whereof the sides have been surveyed with the tacheometer, and which has formed the basis of the map of Central Sumatra accompanying the second report (scale 1 to 100,000).

One assistant in fifty-two days (including interruptions from rain) levelled and brought on to plan 62 miles of road, with an average of 9 stations and 25 neighbouring points observed per mile, in which he was assisted by one native ganger and eight coolies. The accuracy was satisfactory, and greater than could have been obtained by the use of any other instrument. The method used at Sumatra is comparatively cheap. There have been surveyed in full detail, planned and estimated—for the colliery line, 101 miles; in the Highlands, 82 miles; total, 183 miles.

Above 218 miles of main roads have been tacheometered, plotted, &c. There were employed under the Author in one month of railway surveying one hundred and seventy-five engineers, two hundred and sixty Dutch assistants, sixty native assistants, equal to the labour of three complete parties during twenty-three months. Taking five months' labour of one party for the survey of harbours and such incidental work as sounding and boring, &c., sixty-four months of one party have been spent on the railway surveys.

Dividing the time between the colliery railway and the Highland railway in the ratio of 4 to 1, it appears that per month and per party there was surveyed, plotted, and estimated, of the colliery railway 2 miles, of the Highland railway 6·43 miles.

The total cost per mile is for the colliery line £404; for the Highland roads, £125, which compares favourably with the costs of similar works executed in Europe.

A. S. M.

Coal Depôt on the Philadelphia and Reading Railway.

By H. BLANCK.

(Zeitschrift fur Baüwesen, vol. xxvii., pp. 427–440, 547–560.)

The Author in an article on the construction of American railways gives a variety of details about the permanent way. While on the subject of rails, he states that their usual length is 24 feet; but so many advantages have been found to result from the use of rails 30 feet long, that the latter are now almost universally adopted. At the works of the Philadelphia and Reading Company old rails are converted into new ones; the entire make in the year being 30,000 tons, and the proportion of old to new rails two-thirds. The Author gives a description of the process, adding that the results are so satisfactory that other railway companies are introducing the system. An account is given of the above Company's coal depôt at Richmond, near Philadelphia. This immense establishment is situated a short distance from the Delaware, and is used almost entirely for the shipment of coal. The Company possess two rich coal-fields in the Schuylkill district, separated from each other by the Broad Mountain ridge, and connected by an unfavourably situated tunnel, with a single way. As this was far from sufficient for the traffic, communications have been established with the Mahoney fields, across the ridge. The height intervening is 360 feet, and the length of the inclined plane, which forms a parabolic curve, is 2,350 feet. The inclination is, therefore, about 1 in 6½. There are two pairs of rails of ordinary gauge, 14 feet apart from centre to centre, the ascending and descending trucks being on the road simultaneously. The rails rest on longi-

tudinal sleepers, and these again on cross sleepers. On the latter there is an intermediate pair of rails, 3 feet 2 inches apart, and between these, at intervals of 50 feet, guiding pulleys about 1 foot in diameter. The trucks are pushed up, or held back, by small four-wheeled "barneys," to which the steel rope is attached. In order not to interrupt the traffic, the "barneys," when they arrive at the lower end of the inclined plane, run into a depression between the outer rails; the rope, by means of a shifting horizontal wheel, being here attached to a counterweight of 18 cwt., calculated to keep an equal strain between the two ropes while working. The rope is worked at the top by a 500-HP. engine. Ten loaded and fifteen empty trucks can be worked at the same time, at the rate of 20 miles an hour, making a total of two thousand two hundred trucks, at 5 tons of coal each per day. When 2,000,000 tons have been worked, the ropes ($1\frac{1}{4}$ inch and $2\frac{1}{2}$ inches in diameter) are replaced by new ones, even if not worn out. At the lower end of the inclined plane the lines branch out into a fan-shaped network of nearly fifty pairs of rails. These are laid on an embankment about 13 feet high, to a point not far distant from the docks; from this point they are fixed on framings of massive timber, which are planked below, so as to give storage-room for 180,000 tons of coal. There are twenty-one wharves, at which one hundred and twenty vessels of all kinds can load simultaneously. The annual shipment of coal has hitherto not exceeded 2,500,000 tons, but with the means at disposal now from 3,000,000 to 4,000,000 tons can be shipped.

J. J. W.

Swedish State Railways. By P. W. ALMGUIST.

(Ingeniörs-Föreningens Förhandlingar, Stockholm, 1877, pp. 7–20.)

In the Traffic-reports on the Swedish State railways the receipts are given under the two headings of passenger and goods traffic, while the expenditure appears under four, viz., traffic, permanent way, machinery (locomotive and carriage), and office expenses. Hence it is impossible to ascertain directly from the reports what proportion of the net revenue each kind of traffic contributes. The Author gave this information for 1865, and now compares the results obtained for that year with those for 1875.

The hypotheses on which he bases his calculations are—

1. That the cost of working and repairing each class of wagon or carriage is proportional to the train mileage run.

2. That locomotive, traffic, and permanent way expenses are chargeable against each class of traffic, proportionally to the train mileage run by the wagons of that class, and to the gross weight moved.

3. That office expenses are chargeable to each class in the proportion of the sums expended under the other headings.

The following are the results :—

—	Percentage of					
	Total Expenditure.		Gross Receipts.		Net Receipts.	
	1875.	1865.	1875.	1865.	1875.	1865.
On account of passengers .	25·3	30·7	38·1	47·3	61·3	71·9
„ „ „ goods . . .	72·5	66·6	60·3	49·1	38·3	23·1
„ „ „ post and prisoners	2·2	2·7	1·6	3·6	0·4	5·0

On the same hypotheses he ascertains also the receipts and expenditure per train mile as under :—

Per Train Mile.	Expenditure.		Gross Receipts.		Net Receipts.	
	1875.	1865.	1875.	1865.	1875.	1865.
	d.	d.	d.	d.	d.	d.
Per passenger carriage . .	2·23	2·37	5·24	6·09	3·01	3·72
„ goods wagon	2·50	2·37	3·23	2·92	0·73	0·55
„ post and prison van . .	2·06	2·22	2·27	4·99	0·21	2·77
„ vehicle generally . .	2·31	2·36	3·75	3·95	1·44	1·59
„ passenger	0·34	0·28	0·80	0·72	0·46	0·44
„ ton of goods	0·81	1·06	1·06	1·30	0·25	0·24
„ ton of gross weight moved	0·31	0·35	0·47	0·59	0·16	0·24

It also appears, that each engine drew on an average 2·37 times its own weight in 1875, as against 2·34 times in 1865; that the proportion of dead weight to paying load was, on an average, for passengers as 17 to 1, and for goods as 2·66 to 1; and that the paying load averaged only two-thirds of the weight of the engine and tender, or one-fifth of that of the whole train by which it was carried.

M. L.

On the Duration of Steel and Iron Rails.

(Zeitschrift des berg- und hüttenmännischen Vereines für Kärnten, vol. ix., pp. 341–345.)

The following figures refer to the main line of the Cologne-Minden railway, which has a total length of way of 1,357 miles, or double that length of rails in use, exclusive of colliery

sidings. At the end of 1876 more than 90 per cent. of the whole was laid with steel, the substitution for iron, having been in progress since 1864. The effect of this on the maintenance of the line is seen in the following table:—

Renewals in 1870	. . .	7·75 per cent.	of total length.
„ „ 1871	. . .	8·77 „	„
„ „ 1872	. . .	7·55 „	„
„ „ 1873	. . .	8·40 „	„
„ „ 1874	. . .	4·33 „	„
„ „ 1875	. . .	1·04 „	„
„ „ 1876	. . .	1·13 „	„

The rate at which the actual substitution of steel for iron proceeded is given in the following table, representing the number of Bessemer steel rails laid down and removed in each year since 1868:—

Year.	Number of Rails in use at end of Year.	Number of Rails laid during Year.	Removed as useless during Year.	Percentage of length in use.	Rails broken before laying.
					No.
1868 . .	1,853	..	..	..	..
1869 . .	21,867	20,014	31	0·142	3
1870 . .	78,259	56,392	20	0·025	4
1871 . .	139,618	61,359	54	0·039	18
1872 . .	222,844	83,226	93	0·042	41
1873 . .	340,300	117,456	342	0·101	173
1874 . .	452,650	112,350	738	0·158	8
1875 . .	504,634	51,984	347	0·069	2
1876 . .	514,801	10,167	310	0·060	2
			1,935	0·376	251 = 0·049 per cent.

Out of the total of 1,935 rails rendered unserviceable, 1,204 broke through the full section, 227 through the fish-bolt holes, and 504 were otherwise damaged. That the number of removals does not increase, but has substantially diminished since 1874, is accounted for by the fact that these removals are necessitated not so much by wear as by defects in manufacture, which are usually discovered within a short time after the rail has been laid.

In order to obtain accurate data as to the comparative efficiency of different classes of rails, a number of samples from different makers were laid on a part of the line having the heaviest traffic, near the Oberhausen station. The experiment commenced in 1864, and the results obtained up to the end of 1876 were as follows.

The rails were all of the same section, called Calibre IV., and 5,650 millimètres area:—

Description of Rail.	Laid in 1864.	Remaining in 1876.	Average Wear of Head.	Removals in Twelve Years.	
	No.	No.	Millimètres.	No.	Per cent.
Fine-grained iron from Friedrich-Wilhelm-Hütte, Troisdorf	150	29	..	121	80·66
Case-hardened iron from Phönix-Hütte	150	48	4·44	102	68·00
Puddle steel, Funke and Co., Hagen	12	8	4·72	4	33·33
Puddle steel, E. Hösch and Sons, Lenders-dorf	12	8		4	33·33
Bessemer steel, E. Hösch and Sons	149	142	5·22	7	4·70
Bessemer steel, F. Krupp	147	141	5·18	6	4·08
Bessemer steel, Hörder Verein	150	148	4·18	2	1·33

The average wear of the experimental Bessemer rails is 4·86, which represents the effect produced by the passage of 6,500,000 axles of passenger and goods trains, or about 1,340,000 axles for each millimètre of wear.

H. B.

Experiments on Steel Rails. By J. Van Hamel.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., pp. 231–233.)

These experiments were made on steel rails ordered for the Transvaal Republic, and manufactured by John Cockerill and Co., of Seraing. They were of the Vignoles type, weighing 56 lbs. per yard, and of the following dimensions: height, 3·9 inches; breadth of foot, 3·9 inches; breadth of head, 2·2 inches; thickness of web, 0·4 inch. Sixteen rails were experimented on, and the tests and results were as follows:—

(A) The rail was to be placed on bearings 3 feet 7 inches, and receive a blow from a weight of 1,102 lbs., falling freely from a height of 19 feet 6 inches, without showing a set of more than 1·8 inch; and was then to be turned over and straightened back again under similar blows without breaking. The whole of the rails bore this test well, the largest set under the first blow being 2·1 inches. They were subsequently nicked in the foot, and then broken by blows of the same weight; the number of blows required varied from one to eight, the last number occurring with a rail which had been a long time under a hot sun, and may thus have been rendered more ductile.

(B) The rail, placed on the same bearings, was to support a weight of 9·8 tons at the centre for five minutes without showing any permanent set; and subsequently a weight of 27·5 tons under the same conditions without breaking. The whole of the rails bore both these tests satisfactorily, the permanent sets in the second case varying from 1·97 inch to 4·9 inches.

(C) From each charge two small ingots were taken, and forged into bars 0·8 inch square, which when cold were bent double without breaking: the object of this test being to show that phosphorus, sulphur, and silica, were not present in an inordinate degree.

(D) Four pieces were cut off finished rails, forged into square bars, and then turned down to four different diameters, 0·59, 0·63, 0·61, and 0·73 inch respectively. These specimens, each 4 inches long, were then tested separately in a hydraulic press for tensional strength. The three first specimens behaved nearly alike, beginning to stretch sensibly at about 22·2 tons per square inch, and breaking at about 38 tons per square inch, with a final extension of about 18·5 per cent., and contraction at the point of fracture of about 16 per cent. The fourth specimen began to lengthen at about 19 tons, and broke at 34·3 tons: but from the fracture it appeared to have been somewhat overheated, and thus not to give a fair test.

The above results show sufficiently the nature of the steel; which belonged to the category called in Belgium "Très-tendre" or "Tendre," not capable of hardening in water. These qualities have from 0·18 to 0·20, and from 0·20 to 0·28 per centage of carbon respectively, and were used in this case on account of local circumstances, which did not allow of the quality "demi-dur," which is preferred in Europe. This quality has 0·28 to 0·30 per centage of carbon. The charge of raw material used by Messrs. Cockerill when making this steel is given in detail, and also its chemical composition when melted.

W. R. B.

Mallet's Locomotives with Compound Cylinders.

By M. LESTANG.

(Revue industrielle, vol. viii., pp. 393, 394.)

The locomotive stock of the Bayonne and Biarritz railway is constructed with compound cylinders on M. Mallet's system: the first or smaller cylinder to the left side, and the second or larger cylinder to the right side. The engines are constructed like ordinary tank-locomotives, with six wheels, of which four are coupled; they have horizontal outside cylinders, with the addition of a starting valve (*tiroir de démarrage*), by means of which steam

may be admitted direct from the boiler to both of the cylinders, for starting a train, or when full power is required for ascending an incline. In ordinary conditions, steam is admitted from the boiler to the first cylinder only, whence it is exhausted into the second cylinder, and thence into the chimney.

The railway is 5 miles long, and the gauge 4 feet 8½ inches; there is one incline of 1 in 66 for one-third of the length, and there are curves of 440 yards radius. The locomotives, three in number, were constructed by Messrs. Schneider and Co. The dimensions are:—

Area of grate	10¾ square feet
Heating surface of fire-box	80½ „
Total heating surface	483 „
Pressure in boiler	10 atmospheres.
Diameter of first cylinder	9·45 inches.
„ second cylinder	15·75 „
Stroke of pistons	17·70 „
Diameter of driving wheels	47·25 „
Weight of the locomotive empty	15·50 tons.
„ „ in working order	19·50 „
Driving weight	15·20 „

There are fifty-eight trains daily, making a total of 290 miles run per day. On the total mileage run, which amounted to upwards of 30,000 miles at the end of September, the total fuel consumed did not exceed 14 lbs. per mile. The weight of the train was from 40 to 50 tons, rising occasionally to 60 or 70 tons, taken at an average speed of 20 miles per hour. The steam is expanded four times, and neither the stability of the engine nor the force of the draught appears to be affected by the compound arrangement.

D. K. C.

On Lubricating the Flanges of the Leading Wheels of Locomotives.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., pp. 183, 184.)

The rapid wear of the flanges of the leading wheels is an important element in the cost of repairs of a locomotive engine. Various attempts have been made to lessen this wear, especially by giving a more decided coning to the tires; but this device has several disadvantages, and cannot be applied where the leading wheels are coupled to the engine. It has lately been proposed to lubricate the flanges at the point where the greatest wear takes place, and the State railways of Bavaria have experimented extensively on a system of this kind, designed by Herr Fischer von Rösslerstamm, of the Kaiserin-Elisabeth-Railway. The first attempts were made with fixed tablets of hard grease, inserted in casings, which were fastened to the bearing springs of the wheels in such a way that the grease tablets were close to that

part of the flanges where the chief wear takes place. Tablets of three different degrees of hardness were provided, to suit the temperature at different times of the year. Better results were obtained, however, by using tablets of felt, stiffened by thin layers of wood, and saturated with either rape, or "Vulcan" oil, thus obtaining the advantage of being independent of temperature. Experiments were made both with passenger and with six-coupled goods engines, care being taken that wherever two engines were tried against each other they should be fitted with tires of the same make and date, and should as far as possible have the same running duty. The general result after allowing for accidental discrepancies, was to establish that the duration of lubricated as against unlubricated flanges may be taken to be in the proportion of 3 to 2; an advantage so large as to put the cost of lubrication quite out of account. In addition, the noisy grinding of the wheels round sharp curves was quite done away with, and the motion rendered smooth and pleasant. The corresponding saving of wear and tear in the rails is also not to be lost sight of. The lubrication is not applied in wet weather, as the rain forms a natural lubricant, and has also to be suspended in time of snow, which is apt to hang on the tires and clog the lubricating boxes. The apparatus requires no attention beyond the occasional dropping on it of a little oil by the driver; and the fear that the face of the tires might get greasy and lose adhesion has proved groundless, no case of wheels slipping from this cause having been reported. The cost of lubrication with felt and oil has been found to average 3*s*. to 5*s*. per 10,000 kilomètres, or say 12*s*. to 20*s*. per engine per annum.

W. R. B.

Warming Railway Carriages. By F. CLÉRAULT.

(Annales des Mines, vol. xi., 1877, pp. 129–182.)

M. Clérault gives an abstract of a Report by M. L. Regray, addressed to the Administration of the Chemins de Fer de l'Est,[1] containing a detailed account of the systems of warming carriages on the principal European railways, comprising upwards of 60,000 miles, with the results of experiments made on the Eastern Railway of France. A great diversity of opinion exists amongst railway officials as to what constitutes the best system of warming, though it is acknowledged that in England, the common foot-warmer is, by general consent, accepted as satisfactory.

The following is a *résumé* of the cost of the different systems

[1] *Vide* "Le Chauffage des Voitures de toutes classes sur les chemins de fer." par L. Regray, Ingénieur en chef du matériel et de la traction de la compagnie des chemins de fer de l'Est. Publié par ordre du conseil d'Administration avec un atlas de 31 planches. Paris, 1876.

examined; the working cost comprising the charges for fuel, lighting, water, attendance, maintenance, interest, &c.:—

System.	First Cost per Carriage.	Working Cost per Carriage per Mile Run.
	£.	d.
Stove in third class	11·7	0·15
Heated air apparatus	33·5	0·23
Artificial fuel apparatus	28·1	0·43
Steam-heating apparatus	43·0	0·32
Hot-water apparatus in small fixed boilers	27·0	0·225
Hot-water foot-warmers	12·2	0·149

The stove is the simplest and most economical apparatus; but the heat is not equally distributed, and the presence of incandescent fuel is an occasional source of danger. The heated air apparatus is complicated, bad in principle, and injurious to health. The use of artificial fuel (*combustibles agglomérés*), which costs £12 per ton, is too costly; besides, there are the dangers of setting fire to the carriage, and of asphyxia by impure air. Heating by steam, though common in Germany for heating first-class carriages, is not popular in France: the high temperature maintained—about 70° Fahr.—causes a general sense of uneasiness. The system, besides, drawing a supply of steam from the engine, or from a special boiler, is complicated and is not free from danger; and it is liable to accident by freezing in the pipes of communication. The advantage of the system of hot-water apparatus, with fixed boilers, is that, with it, a constant temperature of 140° Fahr. may be maintained under the feet of the passengers, whilst the general temperature in the carriage is maintained at about 20° Fahr. above that of the external air; but the furnace under each carriage is objectionable.

The general conclusion arrived at is, that the feet of the passengers should be warmed by means of hot water contained in foot-warmers, either fixed or movable. Sixteen different warming apparatus are illustrated and described in the article.

D. K. C.

Steam on Street Railways.

(Journal of the Franklin Institute, 3rd series, vol. lxxiii., pp. 379–391, vol. lxxiv., pp. 68–71.)

Accounts of the performances of the Baldwin steam-car and the Ransom steam-car—both of them designed to be applied to existing car stock—are extracted from a report of the Secretary of the Franklin Institute. The Baldwin steam-car was built at the Baldwin Locomotive Works in 1875. The steam-cylinders were placed under the body, connected to a crank-axle, to which the fore wheels were coupled. The hind wheels were free. The

machinery was fixed to an iron bed-plate, bolted to the wooden framing of the car; but the framing proved to be deficient in strength for the purpose, whilst the crank axle was subject to occasional breakage. In the end of 1876, the steam-car was reconstructed. An iron framework was made, on which an upright boiler and the machinery, with outside horizontal cylinders, were fixed, and also the body of the car independently. The weight is carried on rubber springs, with transverse equalising beams. The boiler is of steel, double riveted, to support safely a pressure of 300 lbs. per square inch. The steam-car, loaded, could be moved over the steepest gradients, 1 in 22, of the Market Street line of tramway, Philadelphia, without "stalling" or requiring assistance. It worked regularly on that line every day for four weeks, ending April 18, 1877, running 88 miles per day. The fuel, coal, was consumed at the rate of 8·03 lbs. per mile-run. The car did not require any repair during the run for four weeks. The following is the estimated total cost for working the Baldwin steam-car :—

COST of RUNNING ONE STEAM-CAR (BALDWIN'S SYSTEM) ONE DAY.

	Dollars.		s.	d.
Fuel, 88 miles, at 8 lbs. per mile, equal to 704 lbs., at 4 dollars per ton	1·26	or	5	3
Oil, waste, and tallow	0·25	„	1	0½
Wages of engineers, 16 hours, at 25 cents .	4·00	„	16	8
Repairs and maintenance of steam car . .	1·00	„	4	2
Working cost	6·51	„	27	1½
Daily interest on cost of steam car, 3,000 dollars, or £625, at 6 per cent. per year . .	0·49	„	2	0½
Total cost per day . . .	7·00	„	29	2

Equivalent to 4*d.* per mile run.

In the Ransom steam-car a double-crank axle, with driving wheels, for inside cylinders, is substituted for one pair of the ordinary wheels of a tram car, and the machinery is placed horizontally under the floor. The two cylinders are cast in one piece, connected to the driving axle by means of three bars, which have bearings on the axle, and form the framing of the engine. The forward end of the frame, at the cylinders, is supported by a loop pinned to the bottom of the body; and the engine thus becomes suspended on three points, whilst it is easily removed for the purpose of repair. The machinery, which is accessible through trap-doors in the floor, is inclosed in a casing made perfectly dust-tight so that, at the end of a day's running, the engine is not only free from dust, but is covered with drops of such steam, condensed, as may have escaped through the stuffing-boxes. The boiler, which is upright, is placed a little forward of the fore axle, and the water tank is under the floor at the rear end. To subdue the noise of the exhaust steam, the steam is passed through a muffler, consisting of a box filled with balls or pebbles. The body is 16 feet long, seated

for twenty-two passengers; the length of wheel base is 7 feet. The cylinders are 5¼ inches in diameter, with a stroke of 14 inches. There are 6½ square feet of grate-area, and 116 square feet of heating surface; the working pressure is 120 lbs. per square inch. The car is fitted with a steam-brake. A Ransom steam-car was worked regularly for five months in 1876, on the Coney Island railroad, 4½ miles long. It ran 81 miles per day, at a gross average speed of 13½ miles per hour, consuming 7·4 lbs. of coal per mile-run. The total cost for running 81 miles per day is estimated at 8·31 dollars, or 34*s.* 7½*d.* per day, at the rate of 5·13*d.* per mile-run. Others of Ransom's steam-cars have been at work on the Market Street line, Philadelphia, but they were scarcely powerful enough to cope with the steepest inclines of that line. It is intended to substitute 7-inch cylinders, and to apply steel driving-tires in place of chilled tires, to increase the adhesion.

The cost of running one two-horse car per day is given as 35*s.* The estimated cost for working the Baldwin steam-car was 29*s.* per day, or 18 per cent. less.

D. K. C.

Tramways in Paris. By M. Rousselle.

(Bulletin de la Société de Encouragement, 3rd series, vol. iv., p. 300.)

The concession for a system of tramways in Paris, 66 miles in length, was passed in 1873. The system was divided into twenty sections, comprising a circular line which skirted the outer boulevards, and twenty radial lines to accommodate the more important suburbs. The construction of these lines was divided between three companies: the Omnibus Company, and the Companies of the North and the South. The gauge was fixed at 4 feet 8½ inches, with the object of connecting the goods stations of the railways; but it was found to be impracticable to run a railway wagon on an ordinary grooved tram-rail, the groove being too narrow.

The rails are 3·54 inches wide, comprising a groove 1·38 inch wide, and a rolling surface of 1·57 inch.

The cars of the Omnibus Company are seated for twenty persons inside, twenty-two outside, and six on the platform. They weigh 2·95 tons empty, and from 6 to 6½ tons full. The driver sits on an elevated seat in front, and the entrance is behind; the fore axle is movable on a perch-bolt, and is fixed in position, except when the car is to be reversed at the ends, when the axle is set free for turning. The cars of the North Company are only seated for inside passengers, sixteen inside, with standing-room for sixteen on the two platforms. The weight is 1⅝ ton empty; with load, 4½ to 4¾ tons. The cars of the South Company are seated for sixteen inside, twelve on the two platforms, and eighteen outside. They weigh 2·2 tons empty, and loaded, 5 to 5·2 tons. Each car runs from 53 to 56 miles per day, and is worked with

eight, ten, or twelve horses; each pair making a journey of 10 miles per day. The cars can be stopped by their brakes within from 9 to 11 yards when light, and from 18 to 22 yards when heavy.

Three forms of mechanical power have been used or tried: 1. The steam locomotive (Merryweather's). The boiler is 5 feet 7 inches long, and 2 feet 8 inches in diameter; it contains one hundred and fourteen tubes, making 97 square feet of heating surface. The four wheels are 24½ inches in diameter, and the axles are at a distance of 4 feet 7 inches apart, and coupled. The cylinders are horizontal, and have a stroke of 10 inches. The engine is covered in, and resembles a short car. Coke is the fuel; and the weight in working order is 3½ tons. The traffic on the line between the Mont Parnasse station and the Bastille is worked exclusively by such locomotives. It does not appear that they produce any economy of expenses.

2. The fireless, or hot-water locomotive of M. Francq, which has already been noticed.[1] In the last engine of this kind, constructed by M. Cail, the wheels are 29½ inches in diameter, 4 feet 3 inches apart; and they pass along curves of 50 feet radius. The reservoir is of $\frac{9}{10}$-inch steel plate; it is 3·28 feet in diameter, and 6·56 feet long, and is stamped for 15 atmospheres. It is clad with cork and wood. The steam is exhausted into a cast-iron chamber, whence it passes into a condenser, before escaping into the atmosphere. The performance of this machine is to be completely tested.

3. Mékarski's compound-air engine, which has also been noticed.[2]

D. K. C.

Inclined Tramways at the Fortress of Glatz, Silesia.

By H. Wickfeld.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiv., pp. 228–230.)

Two tramways, worked by drum and wire rope, have recently been established at this fortress to convey in case of siege, war material, &c., between two elevated redoubts. These are separated by a valley through which runs an ordinary road, and across this the loads are taken by road wagons standing on tramway trucks, which descend and ascend the inclines and are so constructed that their tops are level when the wheels are on the incline. This, in both cases, rises at about 1 in 3½ to a total height of 148 feet. They are vaulted over at all parts exposed to fire; but to guard against the consequences of the wire rope being shot away or otherwise broken, a rack is fixed between the rails, consisting of two parallel angle irons connected by bolts passing through the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 289.
[2] *Ibid.*, vol. xliii., p. 383.

vertical table of each; the truck has two hooks attached to it which are kept raised by the draw-rope; but should this break they would fall and at once catch hold of the bolts of the rack, thus bringing the truck to a standstill. The power is supplied by soldiers, working at four long crank handles arranged side by side, and connected to the rope-drum by suitable gearing, going either a slow speed of 16 feet per minute for ascent, or a quick speed, three times the above, for descent. The total weight raised, including the truck, is about 7½ tons, and for this, allowing 40 per cent. loss by friction, about thirty-four men would be required. The cranks are made large enough for this number, but in general a counterbalance is employed for part of the weight, consisti ıg of a loaded truck which runs on a track of narrower gauge laid side by side with the main tramway. The ropes for the transport truck and the counterweight meet at the middle of the drum, where they pass through the circumference and are fastened inside; from thence they are wound round the drum in opposite directions towards its ends, one leaving it at the upper and the other at the under side, so that one is always being wound on as the other is being wound off. These ropes are 23 millimètres (1 inch) in diameter and consist of 49 wires of cast steel. The total cost of the two tramways, exclusive of masonry, was about £3,000.

W. R. B.

On a Rope Tramway at Strasburg. By A. Bleichert.

(Deutsche Bauzeitung, vol. x., pp. 269–270.)

This tramway is in use at Strasburg for removing the earth from a ditch, 22 feet deep, forming part of the new system of fortifications. Starting from the lowest point of the excavation, it is carried first through a short tunnel at a rise of 1 in 10, then passes over a railway (which is protected by a temporary roofing) and thence is led horizontally to its farther or discharging end, the total length being about 1,000 yards. A peculiarity of the system is that the roads, as they may be termed, on which the skips of earth travel are not of wire rope, as usual, but of round bar iron. Of these there are two lengths, 5 feet 9 inches apart—one having a diameter of 1¼ inch for the loaded skips, and the other having a diameter of 1·02 inch for the empty ones. They are welded up into lengths of about 55 yards, and these lengths are afterwards united by steel couplings, having a diameter as little differing from their own as possible. These "roads" are anchored down to the ground at the loading end, but at the other end terminate in chains which pass over pulleys and support hanging weights, sufficient to bring a strain of 4½ tons on the stronger "road," and 3½ tons on the weaker. There are forty intermediate supports of timber (some of them above 100 yards apart), carrying at the top small

grooved pulleys on which the rope actually rests. The skips are made entirely of wrought iron, much like a dredger bucket. They weigh about 290 lbs. and carry 8½ cubic feet, the total weight transported being thus about 1,000 lbs. They are hung on gudgeons, and empty themselves by turning over as soon as a single fastening is loosened. There are special mechanical arrangements for connecting the hanging skip with a small frame above, carrying two wheels which travel on the fixed "road." The whole is connected with a running endless wire rope which communicates the motion. It is ⅝ inch in diameter, is driven by a portable engine at the loading end, and is kept taut by passing round a counterweighted sheave of 5 feet 9 inches diameter, capable of travelling upon cast-iron guides. The speed of the running rope is in general about 4 feet per second. Small steel couplings are fixed on it at intervals of 130 feet, and to these the successive skips are attached—the mechanism both for attaching and disengaging being self-acting. At the discharging end there is an apparatus of iron rails for transferring the skips from one road to the other; by making this portable and providing it with supports it is further utilised for shifting the ends of the tramway and the point of loading so as to follow the progress of the excavation. With the speed of rope and distance between skips given above the quantity of earth conveyed is about 40 cubic yards per hour. The changing of the skips at the loading point (and similarly at the discharging point) is managed by a single workman. Each empty skip, as it comes upon the return road, detaches itself just before it reaches the workman, who receives and pushes it on to one of the lines of rail leading to the face of the excavation. He has already put in position a full skip which has just arrived by the other line of rails; and the same coupling which has conveyed the empty skip picks up the full skip in passing, attaches it to the rope and takes it away along the tramway. Thus the whole number of men employed on the tramway, as apart from the excavation, is only six at the most. The engine employed is of 8 HP., but 2 to 3 HP. is found to be all that is required for the work. The laying down of the tramway was completed, though in the depth of winter, in less than ten weeks; and Herr Bleichert, the inventor, states that he has tramways at work on this system which are 2,400 yards long, with gradients of 1 in 3½, and conveying earth to the extent of 500 cubic yards per day.

W. R. B.

On Traction by Chain and Rope in the Von der Heydt Coal Mine at Saarbruck. By C. VON WEBERN.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxv., pp. 371–372.)

This mine has in different workings four systems of underground traction, two by rope and two by chain, so that it is well adapted

for comparison of the two methods. One of the chain roads (in the "Burbach" adit) is 1,925 yards long, and is worked by an engine of 50 HP., connected by gearing to the driving drums. These were originally made with catches to grip the chain, but it was found that these wore out in six months, and also damaged the chain. The present drums are about 5 feet 6 inches in outside diameter, made of cast iron in two segments, and have a thick lagging of oak set at an angle, and grooved to receive the endless chain. This latter takes one turn and a half round the drum, and is carried over rollers to the end of the tramway, where it passes round a horizontal sheave of which the diameter is equal to the distance between the centres of the two lines. Throughout the length of the road the chain is supported only by the coal trams (which run at an interval of about 30 yards), except where there is an abrupt curve, in which case the chain is guided by two grooved pulleys, one vertical and one horizontal, which are fixed on a masonry pier at the angle. The chain is thus lifted from the trams just before coming to the curve, round which the trams themselves run by their own momentum, and are again taken up by the chain on coming into the straight. There is no means of attaching the trams, the weight of the chain being found sufficient to effect the traction. The speed is about 5 feet per second.

Should a link break, it is at once repaired by the insertion of a spare link made in two sections taken lengthwise. Each of these has a gap in it to enable the adjacent links to be slipped in; and when this has been done the sections are united by pins. This gets over one main objection to chain traction, viz., the delay occasioned by breakages. At this mine the chains (which weigh about 5 lbs. per lineal foot) last from six to twelve months.

The total cost of erecting this tramway (exclusive of the permanent-way materials) was £4,250, of which £2,840 were for the engine and machinery, £762 for chain, and the rest for smaller items.

The other chain road is only 580 yards long, and is used for bringing forward to the screening sheds the trams delivered by a rope tramway at the mouth of one of the adits (the Van der Heydt). As the trams arrive in trains of great length, the chain tramway has to be brought to the very mouth of the adit in order that the last wagons of the train may be attached without hand labour; and it thus overlaps the rope tramway. This is got over by leading the chain over rollers mounted on posts, and making the supports of these rollers movable, so that they can be lowered to enable the chain to take hold of the full trams, or raised on the other side to lift it off those which are returning empty.

The two rope tramways have lengths of 1,900 and 4,124 yards respectively. A table is given showing a detailed comparison of the cost of their working with that of the two chain tramways. The totals (reduced to pfennigs per zoll centner per lineal mètre) are 2·549 for the shorter rope tramway, 3·047 for the longer, 3·811 for the shorter train tramway, and 1·951 for the longer.

The high figure for the first of the chain tramways is of course due to its length being so much below any of the others; and the results are considered as showing a very great economy in the system of chain, as compared with rope, traction.

W. R. B.

Compressed-air Blast for Steam Boilers. By L. E. Bertin.

(Bulletin de la Société d'Encouragement, 3rd series, vol. iv., pp. 529–544.)

M. Bertin estimated, from the results of experiments, that the quantity of steam consumed for compressing air to act as a blast in the chimney of steam boilers amounted to only one-tenth of the quantity required when discharged direct into the chimney. The air-compressor employed by him was positive, consisting of two air cylinders, 24·4 inches in diameter, with pistons, and a direct-action 9-inch steam cylinder, with a common stroke of 15¾ inches. The normal speed was 65 turns per minute. The compressed-air blast was tried on one of the two boilers of the "Résolue," having the following dimensions:—

Area of fire-grates	43·2 square feet.
Heating surface: plate	207·3 " "
" " tubes	1,008·7 " "
" " total	1,216·0 " "
Length of tubes	7·55 feet.
Volume of water	445 cubic feet.
Volume of steam	222 " "
Section of ash-pits	8·17 square feet.
Section of chimney	6·08 " "
Height of chimney above the grates	55¾ feet.
Load on safety-valves	3 atmospheres.

The compartment containing engines and boiler was completely closed to the atmosphere, except by one passage having a sectional area of 9·80 square feet, through which the whole of the air for supplying the boiler was passed. As the experiment was confined to one of the two boilers of the "Résolue," the chimney was divided vertically into two parts, and the half which was used was subdivided into two, to each of which was devoted one blast-nozzle from which compressed air was discharged upwards. A variety of experiments were made on the power consumed and the velocity and supply of air, by the action of the compressed-air blast. It was found that with nozzles having respectively the sectional areas 4·6 and 11·6 square inches (30 and 75 square centimètres), equal duties in velocity and volume of blast were performed for equal expenditures of power. In a series of trials, in which the fires were lighted and the boiler was actively at work, nozzles of six different sections, from 1·55 to 11·6 square inches (10 to 75 centimètres) were employed. The following deductions were made

from the results of the experiments when the engine was working to 18 HP.:—

Section of nozzles . .	10	20	30	40	50	75 sq. centimètres.
or	1·55	3·08	4·6	6·2	7·7	11·6 square inches.
Velocity of air entering stoke-hole, per second	26·6	27·2	27·9	28·5	29·5	29·5 feet.
Pressure of compressed air, in feet of water .	10·7	7·2	5·6	4·9	4·3	3·6 feet
Effective mean pressure of steam in cylinder of blowing engine . .	4·77	3·71	3·11	2·72	2·48	2·25 atmospheres.
Turns per minute . .	51	65·5	78	89	98	108

The velocities above noted are the total velocities attained, and they comprise the element of velocity, 19·7 feet per second, due to the natural draught.

The object of the next series of trials, which were made altogether with the nozzles of 4·6 square inches, was to measure the consumption of fuel and the production of power.

HP. of the Blowing Engine.	HP. of the Engine of the "Résolue."	Coal consumed per hour (Anzin briquettes).	Coal per I. HP. per hour.	Water evaporated per lb. of Coal.
I. HP.	I. HP.	lbs.	lbs.	lbs.
0·00 Natural draft	57·5	213	3·72	10·77
0·96	88·8	289	3·26	8·82
2·00	100·5	315	3·12	8·00
3·00	106·1	321	3·04	7·82
4·20	118·8	348	2·93	7·82
5·00	119·8	374	3·12	7·53
6·00	127·9	400	3·12	7·00
7·40	135·7	420	3·10	7·03

From this table, it appears that the power developed by the engine was more than doubled by the application of the compressed-air blast, the power required for which did not exceed 5 per cent. of the power of the engine.

The rates of combustion and of evaporation have also been increased in a different manner, by completely inclosing the stoke-hole, and blowing air into it by a powerful fan, so as to maintain a pressure or plenum of from 4 to 5 inches of water.

D. K. C.

Shaw's Spiral Exhaust-Nozzle.

(Journal of the Franklin Institute, 3rd series, vol. lxxiii., p. 366.)

The spiral exhaust-nozzle, invented by Mr. Thomas Shaw, is designed to quell the noise of steam blowing off at the safety-valves of locomotives and steam-vessels. A cylindrical coil of

wire is fixed to the end of the escape-pipe, above the valve, of such a length and diameter that, when it is compressed so that the coils come nearly into contact, the aggregate area of the interspaces is much greater than the sectional area of the escape-pipe. The helix is screwed down, adjusted to the required degree of compression, between two discs; and, as a self-acting means of providing some relief, should the interior pressure become excessive, a short helical spring is interposed between the holding-down nuts and the upper plate, to admit of a slight increase of the interspaces. The coil absorbs the vibrations of the escaping steam, which is subdivided and passed through the interspaces. The turns of the coil cannot vibrate to any considerable extent without touching each other, and neutralising the vibrations so that these are not transmitted to the air. The exhaust-nozzle has been favourably judged by a committee of the Franklin Institute, who "find that it accomplishes the object most effectively."

D. K. C.

On Travelling Cranes with Self-adjusting Balance Weights.

By PROF. K. KELLER.

(Wochenschrift des Oest. Ingenieur- und Architekten-Vereines, vol. ii., pp. 250–255.)

In this Paper the Author investigates several designs which have appeared at different times, for automatically adjusting the position of the balance weight of portable cranes. The arrangements discussed are those of Jambille,[1] Michaud and Jay,[2] Schnabel and Henning,[3] Grosse,[4] and Appleby.[5] In some of these cranes the self-acting balance weight is only a secondary consideration, the main object being to weigh the load.

Jambille uses a balance box running on a tail carried out behind the crane in the usual manner, but curved upwards instead of being horizontal; the end of the hoisting chain, usually hooked to the jib-head, is taken over a pulley down to the end of the tail, and round another pulley to the balance box. Suppose the load be too heavy for a given position of the weight, the result will be that the hoisting chain, instead of lifting the weight, will haul the balance weight up the constantly increasing incline till a point is reached where the resistance of the curve is greater than that of the load, when lifting commences.

Professor Keller, following the method first used by Professor Weisz,[6] investigates the equation to the path of the balance weight,

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[1] "Engineering," vol. iii., p. 325.
[2] "Engineering," vol. viii., p. 286.
[3] English Patent, 1875, No. 505.
[4] "Engineer," vol. xxxv., p. 295.
[5] Patent, 1874, No. 1,285.
[6] Zeitschrift des Architekten - und Ingenieur - Vereins zu Hannover, 1873, vol. xix., p. 61.

and finds that it is a circle struck from a centre, which is situated vertically above the centre of gravity of the weight, when in its lowest position. The equation to the curve is $y = -\sqrt{n^2(l-w)^2 - (x-x_0)}$; where the y axis of the co-ordinate system coincides with the centre line of the crane post and the x axis is placed horizontally; n is a constant; l is the radius of the crane, measured from the centre of the post to the centre of the load; $2w$ is the wheel base, or width between the centres of the rails, being always the smallest of these two dimensions; x_0 is the distance of the centre of the weight from the y axis when in the lowest position. The weight would naturally move in the same path if attached to a lever hinged at a point coinciding with the centre of the previous circle, and with a short arm attached to the end of the hoisting chain. This is the plan adopted by Michaud and Jay.

The most theoretically general case is contained in an arrangement by Appleby. Here two weights are employed, one hung from a lever hinged near the top of the side frames, and the second running on a curved path behind the crane, but connected by rods to the first weight and moved by it. The Author in this case finds as equation to the path of the second weight—

$$y = -\sqrt{\rho^2 - (x - x_0)^2} \text{ (C)};$$

where ρ equals the length of the lever, x_0 is the same as above, and C is a constant. This equation represents an ellipse with dimensions depending on the construction. Appleby uses, however, a straight horizontal path.

If the first weight be omitted, but the lever be retained to move the second one, the construction patented by Schnabel and Henning is obtained. A second design, by Appleby, is somewhat similar to that of Jambille, but the pull is exerted by a chain attached to the tie-rods instead of the hoisting chain, part of the strain being taken by a spiral spring. In practice the weight never runs out quite to the theoretical point, in consequence of friction, and this has to be allowed for by taking a rather larger margin of safety in the calculations.

W. P.

The Danks Furnace at the Millvale Works, Pittsburg, Pa.

By JOHN I. WILLIAMS.

(The Metallurgical Review, New York, vol. i., pp. 37–58.)

The Author, who is superintendent of the Millvale Works of Messrs. Graff, Bennett and Co., at Pittsburg, Pa., U.S.A., has had much experience in the management of the Danks puddling furnace, and considers that by the alterations he has carried out in many of the details of its construction, and by the mode of working he adopts, it has now been rendered a practical success.

In the quality of the iron produced it has no equal; but as originally brought forward, by Mr. Danks, it was liable to very frequent breakages in work, which involved difficult and costly repairs. The Author has chiefly endeavoured to avoid these breakages, and to render the repairs less expensive.

The general construction of the furnace is so well known that it need not be described here. Some of the chief alterations made in it, which are illustrated in the Paper by two woodcuts, are the following:—

(1) An increase of 50 per cent. in the grate surface.

(2) Placing the body of the furnace at right angles to the fire-place, the two being connected by a movable curved flue-piece, so that the fire end of the furnace may be more readily got at for repairs.

(3) The adoption of simpler forms (and of a better quality) of bricks, for the arches over the fire-bridge and in the flue-pieces, and of a firmer mode of keying up the arches.

(4) Alterations in the forms of several of the castings, so as in some cases to render them stronger, and in others to give more freedom for expansion, or to allow of the more ready replacement of the pieces when broken.

(5) An alteration of the flue end of the furnace, so as to admit of a more free expansion of the fettling. In Mr. Danks' design, the ends were so nearly at right angles to the axis of the furnace, that the end rings (through the expansion of the fettling, when repeatedly cooled down and reheated) were constantly being broken, or the rivets started. The Author now makes the end ring next to the flue so much more conical, that the fettling, in expanding, slides up it, and the ends are thus relieved of a great part of the strain to which they were formerly exposed. The more tapered form of the end admits also of keeping it more thoroughly cooled, by water, without the risk of any getting into the interior of the furnace, and cooling it, or injuring the quality of the iron.

(6) One of the most important of the improvements made has been in the driving engines. Those first put up gave constant trouble, and have been replaced by others of greater power, more readily handled, approachable at all points for examination, and less expensive in repairs. One pair of these have been running for more than three years, and have not yet been even overhauled or repacked.

Six charges, each of 900 lbs. of pig, are worked in each furnace per shift. The melting occupies about fifty minutes. The metal is then "thickened," by means of either slag or water, after which a heavy fire is put on, and the rotation of the furnace quickened. In a short time the charge is in violent ebullition, and within about seventy minutes from charging the metal has become granulated and massed together. Balling is then commenced, and the ball when ready is carried by a fork, suspended from overhead runners, to the squeezer. The cinder is not tapped out, in the course of the operation, as is done by Mr. Danks. The squeezed ball is either

reheated, and then rolled into broad puddled bars, or if small blooms or slabs are required, it is taken from the squeezer to the hammer, hammered flat and cut into suitable pieces, put into a heating furnace for a wash heat, and then returned to the hammer, and hammered to the shape desired.

To do the entire work for ten furnaces, including the breaking and wheeling in of the pig iron and the squeezing of the balls and rolling into puddled bars, a puddler and underhand to each furnace, a labourer to every two furnaces, and eleven other men (in all thirty-six men) are required, besides a mason and helper, and a foreman to oversee the whole.

In thirty-seven days worked, during April and May 1877, 1,941 heats in all were made, with nine furnaces, working single shift; 1,746,900 lbs. of pig were charged, and 1,693,010 lbs. of puddled bars made, the loss being 3·08 per cent.; the total amount of coal used, in working the furnaces during these two months, was 40·34 bushels, per ton of puddled bar made; the ore employed for fettling was 484·52 lbs. per ton of bar; the scrap used was 49·89 lbs. per ton, and the scale 55 lbs. per ton. It is easy to obtain a greater yield of bar than that above stated, but this can be done only at the expense of the quality of the metal produced. Further economy in working will be obtained when arrangements are completed for melting the fettling in a separate furnace, and the pig iron in a cupola.

The quality of the iron obtained is most satisfactory. It may be rolled into sheets $\frac{1}{1850}$ inch in thickness; bars 2 inches by 8 inches, or up to 3 inches square, may be bent close without showing a crack; and bars with a fibre as fine as silk may be bent close, without breaking, after nicking them with a chisel, while other bars may be made from the same pig, showing a fracture as granular as coarse steel and yet also capable of being bent down close, when not nicked, without fracture. Copies are appended of several reports of tests of the iron, in bars and in plates. Bars 0·96 inch by 0·9 inch, and 6 inches long between datum points, had an ultimate tensile strength of about 60,000 lbs. per square inch, and stretched about 1·8 inch before fracture.

W. H.

On a New Furnace for Mercury Ores. By A. Pichler.

(Zeitschrift des berg- und hüttenmännischen Vereines für Kärnten, vol. ix., pp. 332–338.)

At the mines of the Illyrian Quicksilver Company, near Neumarktl, in Carinthia (of which the Author is the Director), mercury ores occur interspersed through limestone in such a manner that the average assay of the rock treated does not exceed 0·8 per cent. (18 lbs. of mercury per ton of rock). As this is not rich enough to bear the cost of complex methods of dressing and smelting, the furnace to be described has been designed with a view of working continuously,

and without any special requirements in the way of machinery or skilled labour. It consists essentially of a cylindrical shaft, 30 feet high, and 4 feet 3 inches internal diameter, formed of an outer shell of boiler plate 0·315 inch thick, with an internal lining of firebrick-work 6·3 inches thick; an intermediate space of 0·4 inch, allowed for expansion of the brickwork, being filled with graphite. This is mounted on a pedestal of masonry, and is provided with three openings, placed radially and equidistant at the bottom, for drawing the exhausted rock, and a charging and gas-collecting arrangement at the top, all of which can be closed hermetically when the furnace is at work. The charging apparatus consists of a cast-iron funnel, formed by a cone with a cylindrical tube descending some distance into the gas-collecting space in the furnace, closed by a movable cone, or "bell," at the bottom of the tube, a parallel cone at the neck of the funnel, and a flat plate covering the outer rim, secured by a water joint. Each of these is manipulated by an independent system of suspension chains and counterpoises, so that in charging, two of the three stoppers are always closed. The gases are taken off by a side tube and down-come as in an ordinary blast furnace, and pass subsequently through a pair of serpentine condensers, formed of cast-iron tubes kept cool by an external circulation of water, two large chambers, and an inclined system of wooden labyrinth flues, terminating in a tower with a waterfall blast or trompe. The total length travelled by the smoke before it is discharged is about 350 feet, the draught being regulated by a damper placed at the end of the flue between it and the water blast.

The ore, as prepared for smelting, is divided into coarse and fine classes, the former including pieces from double the size of the fist, down to that of a walnut, and the latter everything smaller. There is no constant relation between the two, the large varying from nine-tenths to one-half of the total produce of the mine. The working is generally similar to that of an ordinary continuous kiln. The charges are introduced in the proportion of 11·3 cubic feet of ore to 1·75 cubic feet of charcoal, the draught being so arranged that seven to eight charges pass through daily. In working, a quantity of ore equal to half a charge is constantly kept in the top funnel, and at charging time is dropped into the tube above the lower bell by raising the top valve. The top cover is then opened and the charcoal is dropped into the tube, and upon it the second half-charge. The top valve is then closed, a third half-charge is thrown into the top funnel, the cover lowered and luted; the whole operation requiring about four minutes; after which the lower valve is opened, and the materials in the tube are allowed to drop into the furnace. After this an equal volume of spent rock is drawn at the lower passages, the operation being repeated at intervals of one hour and a half to one hour and three-quarters. As the yield of mercury depends very greatly upon the management of the draught, great care is required in regulating the opening of the damper. For this purpose gold plates are inserted at the end of the condenser

flue and in the drawing passages. If the draught is too strong, mercury is carried over and whitens the plate at the end of the flue; if it is too weak, the metal shows itself on those in the drawing holes; but when properly regulated, none of the exposed plates are in any way tarnished. The actual opening of the damper varies from 0·6 inch to 3·15 inches, according to the proportion of small ore in the charge. The auxiliary water blast has not yet been found necessary in practice. The capacity of the furnace corresponds to twenty-three charges; each charge, therefore, is forty-six hours in passing through, which time is found to be amply sufficient to exhaust the mercury in the stone. As the latter contains carbonate of lime, no flux is necessary. The mercurial soot, containing 50 per cent. of mercury, obtained in cleaning out the condensers is worked into balls with lime and charged with the ore.

During a working period of five months, 9,966 lbs. of mercurial products were obtained from the various parts of the condensers. Of this the first length of 70 feet gave 4,382 lbs. during the working, and 3,535 lbs. on cleaning up; or together about 80 per cent. of the total. A second length of 100 feet, including the first half of the condenser, gave 1,599 lbs.; a third, of about the same length, being the second half of the condenser, 407 lbs.; and the ultimate system of soot chambers and tail flues only 42 lbs. The proportion of liquid mercury to soot obtained was as 1·8 to 1 during the working, and 1 to 3·5 on clearing up, and the whole produce 39 of the former to 61 of the latter.

H. B.

Protecting the Linings of Blast Furnaces. By J. D. Weeks.

(The Metallurgical Review, New York, vol. i., pp. 87–92.)

In modern closed-top blast furnaces, especially those working rich hard ores, with coke for fuel, and making a large amount of iron per week, the upper part of the lining has been found to wear out long before the rest, and to require constant watchfulness and repair. This is chiefly due to the battering and abrading action of the charge. Where the ordinary bell or cone plan of charging is adopted, the large lumps are thrown against the lining, not only pounding the brickwork, but making the abrasion, as the charge descends, much greater, on account of the increased size of the lumps that rub against the sides.

The upper part of the lining, when thus worn out, is frequently rebuilt while the furnace is still in blast, but the rebuilt portion is never so strong as the original lining; and much attention has been given to plans for preventing this rapid wear.

Alterations in the mode of charging, so as to distribute the charge thoroughly, without the battering action on the brickwork,

have been adopted with success, and several of these are mentioned and briefly described in the Paper; but it is often desirable to check the wear of the lining without interfering with the mode of charging, when this in other respects works well.

In some cases, the lining near the top has been protected by building short lengths of pig iron into it, but more often cast-iron plates of different forms, built in between the courses of bricks, are used. At the Lucy furnace, Pittsburg, T-shaped pieces, cast to the circle of the furnace, were employed, the shank being built in between every other course of bricks, and the head covering two courses; but it was found, on blowing out, that only the portions of the castings between the courses of bricks remained intact, and, in rebuilding, merely flat pieces of iron, in the joints, have been put in, without the cross parts covering the faces of the bricks. At the Glendon Ironworks, Easton, Pa., angle plates 1 inch thick and 6 inches each way, over all, are built in above each course of the lining, for a depth of 15 feet from the top: the bricks are 6 inches thick, and the angle plate covers 5 inches of the face of each brick. At the Thomas Iron Company's furnaces, similar angle plates, 1¼ inch thick, and covering the whole face of each brick, are used for a depth of 6 or 8 feet, where the greatest wear occurs; and in the Dunbar furnace, at Dunbar, Pa., castings of a channel-shape, four of which complete the circle, cover similarly the whole faces of the large lining bricks used.

W. H.

The Production of Zinc in Blast Furnaces.

By A. LENCAUCHEZ.

(Mémoires de la Société des Ingénieurs civils, 1877, pp. 568–580.)

The tension of the vapour of zinc, even at a high white heat, does not appear to be much in excess of the pressure of the atmosphere; and it is thus probable that if a blast furnace, for zinc, were worked in a chamber containing air at a pressure of 3 or 4 atmospheres, the metal, instead of passing off as vapour, would flow from the hearth like cast iron, lead, or copper. The cost, however, of such a furnace, and the difficulty of working it, put it beyond reach, and, for the present, if zinc ores are to be worked in blast furnaces at all the metal must pass off as vapour, and be condensed from the gas.

When a current of carbonic oxide is passed through a porcelain tube filled with oxide of zinc, and then heated to whiteness, the following reaction takes place:—

$$ZnO + CO = Zn + CO_2,$$

the zinc being reduced, and carbonic acid formed. As the zinc vapour, however, passes along in the current of gases to a cooler

part of the tube, its affinity for oxygen reasserts itself, and the converse reaction ensues,—

$$Zn + CO_2 = ZnO + CO,$$

the only result of the operation having been to drive the oxide from the hotter to the cooler portion of the tube.

Oxide of zinc is also readily reduced, at a white heat, by blast furnace gas, containing 24 per cent., by volume, of CO and 12 of CO_2. The gas, after the reaction, contains equal volumes of CO and CO_2. But as the zinc vapour is carried along by the current, when the temperature of this falls below a clear cherry-red heat, (about 1200° C. or 2190° Fahr.), the reducing action of the CO ceases, and the CO_2 in the gas energetically attacks the metal, transforming it again to oxide. Thus, in this case also, there is no practical reduction of the oxide, but only its displacement to the cooler part of the apparatus.

The reactions, on heating sulphide of zinc in a retort, in admixture with carbon, are precisely similar. The vapours of zinc and of sulphide of carbon pass off together to the condenser; but as soon as their temperature falls to below 500° C. (932° Fahr.) the sulphide of zinc is reproduced, and the carbon deposited in the form of lamp-black. In the presence of air the products would be oxide of zinc, sulphurous acid, and carbonic acid. Ores containing intimately intermixed blende and galena might thus be advantageously treated, in some cases, in order to separate the metals, by smelting them directly in a cupola. The fused sulphide of lead would be tapped from the hearth, and the oxide of zinc might be collected, from the gas, in suitably arranged depositing chambers and washers.

In order to determine how small a proportion of CO_2, in the gases of a blast furnace, would oxidise zinc vapour, the following experiment was tried. A vertical retort, 8 inches in diameter and 11·8 feet high, was heated to whiteness, through a height of 10 feet, and filled with red-hot charcoal. Air at a temperature of 400° C. (752° Fahr.) was blown into this through a ½-inch pipe. After having traversed the whole height of the retort, in contact with the charcoal and at an average temperature of 1600° C. (2912° Fahr.), the escaping gas still contained 0·5 per cent., by volume, of CO_2. The gas was passed, from the retort, through a porcelain tube, also heated to whiteness, and containing zinc in ebullition, and thence through a condenser. The greater part of the zinc was deposited in the condenser, but a portion of it was in the form of what is termed zinc fume (*zinc gris*), a fine grey powder, consisting of extremely minute particles of metallic zinc, powdered over and kept from uniting by about 5 per cent. of oxide; and the escaping gas did not contain a trace of carbonic acid. A very small proportion of carbonic acid, mixed with two hundred times its volume of neutral and reducing gases, is thus sufficient to oxidise zinc vapour at certain temperatures.

It is evident from this, that zinc reduced in a blast furnace (the gases of which contain on the average one volume of CO_2 to two of CO) can be obtained only in the form of fume, and that even this will be further oxidised, unless the gases are cooled very rapidly, from above the temperature at which oxidation begins (about 1200° C.), down to 300° C. or 400° C., below which it ceases to be troublesome.

To cool the gases with the needful rapidity they might be passed through a tubular condenser, like the barrel of a locomotive boiler, with tubes about 11 feet long. If the velocity through this were 33 feet (10 mètres) per second, the gases would pass through it in one-third of a second, and scarcely more than 5 to 7 per cent. of the zinc would be oxidised. The pulverulent zinc fume would be deposited in the condenser, which would have to be changed every ten to fifteen minutes. The change might be effected in three or four seconds, and the fume might be brushed out from the condenser that had been in use, into a sheet-iron truck, and taken to the melting shop. The gas from the condenser should be passed through depositing chambers, and might then be burned under the boilers.

To test how far this mode of working is practicable, the Author constructed a small cupola 5 feet high by 18 inches in internal diameter, and fitted it with a condenser, formed of a single tube 8·2 feet long and 1·6 inch in diameter, kept cool by water. The cupola was charged with charcoal, mixed with calamine such as is ordinarily treated in zinc-works, and on distilling off the zinc, 90 per cent. of the amount contained in the ore was found in the condenser. The zinc was almost entirely in the form of fume, containing 90 to 95 per cent. of the metal, a few particles only being as large as grains of corn.

Fume of this kind is produced, in greater or less quantity in every mode of distilling zinc. It is scarcely as heavy as water, volatilises when heated in a close vessel, without becoming liquid, burns rapidly when set fire to, and decomposes water at ordinary temperatures. Submitted to compression, by a screw or hydraulic press, it acquires all the appearance of cast zinc, and its density is increased to 5 or 6, that of the cast metal being 7; but the compressed blocks are very fragile and wanting in tenacity, and they oxidise slowly when kept exposed to the air. A block 2·75 inches in diameter by 7·9 inches in height becomes oxidised to the centre in the course of six months.

Such compressed blocks of fume possess the valuable property that the metallic zinc contained in them melts and flows out, when they are heated, without dissolving the intermixed foreign matters. The block shrinks in volume as the metal flows from it, and the foreign substances, oxide of lead, oxide of iron, ashes from the fuel, &c., are left behind as a sort of skeleton; that from a block 2·75 inches in diameter being often not larger than a pencil. The metal so obtained, by liquation from the compressed blocks of fume, is thus as pure as that ordinarily produced by

a second distillation, and much superior to that made, from the same fume, by the Montefiore process, in which, by the pressure and agitation to which the metal is subjected, during the fusion, these impurities are in great part incorporated with it. The fume produced, in all methods of distillation, may be advantageously treated in this way.

In conclusion, the plan of working zinc ores in a blast furnace is likely to be profitable only in case ores should become anywhere procurable at a low price (8*s.* to 12*s.* per ton), yielding 6 to 10 per cent. of zinc, and 25 to 30 per cent. of iron.

The ordinary prices of rich zinc ores, at the present time, render such a mode of working them quite impracticable.

W. H.

On the Treatment of Oxidised Ores of Nickel.

By J. GARNIER.

(Memoires de la Société des Ingénieurs civils, 1877, pp. 441–450.)

The ores of nickel found in New Caledonia are hydrated silicates of nickel and magnesium, of a peculiar green colour, and occurring as layers, strings, and nodules, embedded in serpentine. The following are analyses of three samples:—

	(1)	(2)	(3)
	Per cent.	Per cent.	Per cent.
Protoxide of nickel	3·50	8·50	18·50
Protoxide of iron	5·18	2·50	3·50
Lime	2·20	17·28	2·65
Magnesia	26·65		15·75
Silica and other insoluble matter	41·75	57·50	50·00
Water	21·25	14·50	10·00
	100·53	100·28	100·40
Nickel	2·75	6·60	14·62
Iron	4·03	1·94	2·45

It is probable that similar ores exist, associated with serpentines and diorites, in other parts of the world, though they have not hitherto been noticed; since from their want of lustre, and their low density when not exceptionally rich, they may readily have been overlooked.

The ore is screened and hand-picked, as, on account of its low density and friable character, it cannot be concentrated by washing, and the finer portions are then crushed and agglomerated.

Two methods of obtaining the metal from it are in use. The first is that of producing a carburet of iron, more or less rich in nickel, or even a nearly pure carburet of nickel, by smelting the ore in a cupola or small blast furnace, as cast iron is ordinarily made, and subsequently removing the iron by cupellation. The

second, which is sometimes preferable in the case of poor ores, is fusion with reducing agents and materials containing sulphur or sulphur and arsenic, such as iron pyrites or sulphate of lime. This yields a sulphuret of nickel and iron, similar in composition to the sulphuretted ores of nickel that are commonly worked. By a suitable regulation of the process, a great part of the iron may be slagged off, and the nickel concentrated in the regulus, which is of the following composition—

	Per cent.
Nickel	50 to 70
Iron	25 to 15
Sulphur	25 to 15

The subsequent treatment of this regulus is a part of the ordinary metallurgy of nickel, and need not be described.

The cupola used for obtaining the metal in the form of a carburet of nickel and iron is about 4 mètres (13 feet) high, and is blown with cold air at a low pressure. The hearth is small, and arranged so that the metal in it shall be maintained at a high temperature. Under these conditions the nickel is readily reduced and carburetted, while a greater or less proportion of the iron passes into the slag. The carburet of nickel and iron is more fusible than ordinary cast iron. In smelting rich ores, such as that of which the composition is given in No. 3 of the above analyses, it is possible, by adjusting the amount of blast, and other conditions of working, to obtain an alloy of any degree of richness, up to a pure carburet of nickel, nearly free from iron. An ordinary composition of the alloy, yielded by ore containing equal amounts of nickel and iron, is—

	Per cent.
Nickel	60·90
Iron	33·35
Silicon	0·85
Carbon	3·90
	99·00

Poor ores, containing at the same time little iron, are smelted with the addition of so much oxide of iron as will render the slag fusible, and will give at the same time a yield of cast iron equal to about 15 per cent. of the weight of ore charged. The loss of nickel, which would occur in smelting these ores alone, is thus prevented.

The carburet resulting from this first fusion is refined by remelting it on the bed of a reverberatory furnace, either alone, when pure nickel is required, or together with copper to produce alloys suitable for making German silver. The oxidation of the carbon, silicon, and iron soon begins, and is aided by the addition of oxidising agents, such as oxide of copper or of manganese. The slag formed is skimmed off at intervals, samples are taken from the bath, and when the metal appears to be free from iron it is cast into ingots.

The Author has been engaged for some time in experiments on the production of useful alloys of nickel and iron, but has hitherto found great difficulty in making these of reliable quality, on account of the marked effect on the properties of the metal of small amounts of impurity. W. H.

Hydraulic Mining in California.[1] By A. J. Bowie, Jun.

(Engineering and Mining Journal of New York, vol. xxiv., pp. 64, 89, 107, 128, 153, 169, 188, 203.)

This Paper, though not in itself a full and clear exposition of the subject, gives information on some points in connection with it supplementary to that contained in the memoir by M. Ed. Sauvage.[2]

The beds of gold-bearing drift, in California, occur at intervals along the western slope of the Sierra Nevada, from Shasta in the north to Kern County in the south; the most extensive deposits being those in Plumas, Sierra, Placer, and Nevada Counties. The lowest portion of a gravel deposit is, in almost all cases, the richest; thus while the top gravel, in some instances in which it has been worked separately, has yielded gold to the value of only 2 or 3 cents per cubic yard, the bottom gravel from the same deposit has produced frequently $1, $2, or more.

The general mode of opening out and working a hydraulic mine has been described in the abstract of the Paper above mentioned. Particulars are given in the present Paper of the lengths, dimensions, and grades of the tunnels and sluices at different mines, the distribution of the gold in the sluices and undercurrents, the proportion of mercury lost, and the consumption of water.

The water used is measured by the "inch." The value of this varies in different districts; in some it is the amount discharged through an opening 1 inch square, in a 2-inch plank, under a head of 6 inches above the opening. The Smartsville "miner's inch" is measured by a horizontal orifice 4 inches high, with 7 inches head of water above it; thus an opening 250 inches long by 4 inches high, and with a head of 7 inches above the top of the orifice, would discharge 1,000 Smartsville miner's inches of water, each equal to a flow of 1·76 cubic foot per minute, or 2,534·4 cubic feet in twenty-four hours. At the North Bloomfield and La Grange mines, the form of the opening used is different, and the "inch" of water as measured there is equal to a flow of from 1·5 to 1·57 cubic foot per minute.

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[1] Read before the American Institute of Mining Engineers, in May 1877. This article is reproduced in extenso in Engineering, vol. xxiv., p. 354 *et seq.*

[2] Annales des Mines, vol. ix., p. 1. *Vide* also Minutes of Proceedings Inst. C.E., vol. xlv., p. 321.

Illustrations are given of the form of nozzle through which the jets of water, 7 to 9 inches in diameter and often under a head of pressure of 300 or 400 feet, are launched against the banks of gravel. The Bowman Dam, now being completed by the North Bloomfield Mining Company, on the head-waters of one of the branches of the Yuba river, is described at some length, and its construction illustrated by several woodcuts. The maximum height of the dam on the lower side is 100 feet, and its extreme length is 425 feet. It rests on a solid granite bed rock, and is constructed chiefly of dry stone-work, faced with heavy walls of dry rubble stones of large size. The slope of the face walls is about 45°. Ribs of cedar, 8 inches thick, are built into the up-stream face walls, and tied back by $\frac{3}{4}$-inch rods 5 feet long. To these ribs a planked skin, of heart sugar pine, in planks 3 inches thick and 8 inches wide, with planed edges, is firmly spiked. This is put on well seasoned, and swells sufficiently to make the face practically watertight, without either battens over the joints or caulking. At the bottom, the plank skin is fitted closely to the bed rock, and caulked with pine wedges. There are three thicknesses of plank (9 inches in all), placed on the lowest 25 feet of the face; two thicknesses (6 inches) on the next 35 feet, and one thickness on the upper 36 feet. It is expected, from experience elsewhere, that this planking will remain sufficiently sound for twenty years, and then it may be readily replaced.

In working hydraulic claims, boulders are frequently met with, which cannot be moved by hand. To facilitate the removal of these, a strong derrick is used. This has frequently a mast 100 feet high, and a boom 92 feet long. It is kept in position by six guys of galvanised iron wire rope, $1\frac{1}{8}$ inch in diameter, which are held by double capstans. The derrick is not taken down when moved; it can be readily shifted 100 feet in ten hours. The hoisting is effected by a "hurdy-gurdy wheel," 12 feet in diameter, worked by a jet of water under pressure. Using 30 inches of water on the wheel (about 45 cubic feet per minute), stones weighing 11 tons may be lifted. Illustrations are given of the wheel and hoisting gear. Similar wheels, up to 18 feet or more in diameter, are used also for other purposes, such as driving stamps; their efficiency is from 0·35 to 0·45 of the theoretical power of the water used.

A table is added of the total amount of gravel washed in each of fifty-two workings, the gross yield of gold, the yield per cubic yard, and the average height of the banks in which the deposits are worked.

The total cost of "hydraulicking" varies from $0·02 to $0·06 per cubic yard of gravel turned over; the work being done most cheaply where the banks worked are high, the water pressure heavy, and the grade of the sluices moderately steep.

W. H.

Boring by Rope in the United States. By H. ALTHANS.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., pp. 29–39.)

During the sixteen years ending 1874, 10,499 bore-holes were sunk in the Pennsylvanian oil district, and at the time of the Author's visit these undertakings were being prosecuted with renewed activity, the production of oil increasing notwithstanding the shorter "life" of a well as compared with earlier periods. These bore-holes are often of great depth (over 1,600 feet), and vary from 4 inches to 8 inches in diameter, according to circumstances. Naturally, the execution of such a large amount of similar work has led to a combination of gearing and tools, giving extraordinary results with regard to simplicity and economy; so that, although the apparatus is comparatively of a primitive character, it presents features of interest.

The offtake legs are made of an open framework of 1½-inch and 2-inch pine planks, from 60 to 72 feet high, erected on solid oak sill pieces. Behind this erection is placed a 12 to 15-HP. engine, working a belt round a sheave fixed in the middle of a main axle placed in front: this axle (4½ feet by 3½ inches) has, at its right extremity, a crank for working the boring lever; at the other end is a rope pulley which is connected by an endless rope with the boring rope roll placed on the opposite side of the hole. This roll is 12 feet long and about 13 inches in diameter, with grooved wheels at either end, one of which is acted upon by an iron rod, fixed with staples into the ground, serving as a brake; the other receives the endless rope as above. This rope—an ordinary hempen one, with a hook attachment admitting of proper tension—is employed instead of a belt, as, at the distance of 30 feet between the transmission wheels, it works in the grooves at less tension and at greater velocities without the same tendency to fly off, while it admits of being put in and out of gear with much greater facility. The band pulleys on the engine and main axle are, respectively, 28 inches and 84 inches in diameter, so that at the ordinary speed of the engine (one hundred and twenty strokes) the latter revolves forty times; the rope pulleys on the main axle and roll are 5 feet and 7 feet, the latter thus making twenty-nine revolutions per minute.

The beam for working boring gear (24 feet long by 18 inches wide, 30 inches deep in the middle and 18 inches at each end) is fixed on a strong upright stayed frame, the carriages being fastened to the beam and working on gudgeons placed on the frame. The connection with the crank of the main axle is effected by means of an iron collar loosely hung on the end of the beam, and prevented from shifting by pins on either side; the under side of the collar is reduced to a fork which receives removable pieces of hard wood, and the stroke is variably adjusted to different pin-holes in the crank.

The "reel" for working the sludger or "sand-pump," a wooden axle 8 feet by 8 inches, has, at the end corresponding with the belt pulley of the main axle, a bevel wheel, the gudgeon of which works in an upright lever actuated by a horizontal rod from near the brake wheel of the rope roll where the man in charge is stationed. In one direction the bevel wheel is thus brought in contact with the belt pulley, and in the other it is forced against an upright post serving as a brake; the bevel is to give the necessary angle to the roll for a proper lead, the "reel" being entirely to the left-hand side and out of line. This friction wheel being only 2 feet in diameter, the sludger roll makes one hundred and forty revolutions per minute.

The rope, for boring (about $1\frac{3}{4}$ inch in diameter) is fixed by means of a screw clamp, hung on the end of a lengthening screw attached to a hook on the end of the beam, and has at the lower end a socket with a box end for the necessary rods. These consist (there being an intermediate "jar piece") of about 46 feet of $3\frac{1}{2}$-inch round rods, the lower piece next the chisel having, however, four longitudinal ribs or bosses. The aggregate weight of these rods, including jar piece and chisel, is from 16 to 20 cwt. On account of the uncertain rotation of the chisel (there being no arrangement for uniform rotation), by the twisting or torsion of the rope, it is necessary to "follow down" with a rounder every time, and for this purpose three or four kinds are used, consisting of differently formed bits connected to a segment or segments of a circle, or, as in the case of a "hollow reamer," of a complete circular cut. Of the "fishing tools," one, formed of a simple rod with notched projections, is used for extracting pieces of rope; the others are variously adapted for bringing up broken rods. The sludger is of ordinary construction, with a bottom valve, but it has the peculiarity of being attached to a forked rod, holding at its lower end a bucket, so that in the course of working up and down the latter assists in drawing the silt.

The operation of boring is conducted by four men (two in a shift) working twelve hours. One of these has charge of the boiler and machine, manipulates the sludger, puts the transmission rope in and out of gear, works the brakes for the boring gear, and fixes them with a key when raised to the surface. The other man screws and unscrews the boring rods and chisels, clamps the rope, puts the lever in and out of gear, places the rods aside, attaches a cord to the lever to work the bellows, and sharpens and tempers the tools, and generally keeps all the boring gear in order. The raising of the boring gear and sludger occupies about one minute, and the lowering of the same half a minute in a 300-yard hole; an average advance of 13 yards is made (at a depth of 300 to 500 yards) in twenty-four hours, and a hole 500 yards deep can be put down within thirty-six days. Similar results are attainable in the hard silurian limestones in Canada.

The lining of the holes generally consists of $5\frac{5}{8}$-inch tubes, the the box end of these being bell-shaped so as to facilitate the

entrance of the pin end. To make the seating watertight a leaden ring, or seed-bag, is provided on the end of the tubing, but owing to these methods being uncertain, an ingenious "water-packer" is often employed. This consists of a short length of tubing, having at the lower end a small removable flange, in the middle a small boss, below which is a left-winding screw, while the top screws on to the column of tubes. A circular piece of leather with pieces cut out of the circumference, and a hole in the centre so as to pass on to the tube, is put on at the lower end, and the flaps are riveted to a thin iron ring working loosely above the boss. A foot ring provided inside with a left-hand thread (to correspond with the screw in the middle of the tube), and having its outside cut at intervals and bevelled off at the bottom, is then screwed up in the middle of the tube, and holds the leather piece against the boss. The lower flange being then put on, the whole is freely lowered on to the seating; but as soon as the foot-ring reaches the same, the pressure of the water forces the leather against the sides of the hole and downwards in the cuts, and into the underset caused by the bevel of the ring. The object of the left-hand screw is to enable the foot-ring to be released without unscrewing any of the upper joints when it is required to draw the column. When unscrewed, and the column lifted, the foot-ring falls on to the flange.

The cost of a bore-hole 1,641 feet (500 mètres) deep is given:—

Erection of woodwork	600	dollars.
Machine and boiler	1,000	„
500 running feet of 5⅛-inch tubing	1,100	„
	2,700	„
Cost of boring, inclusive of maintenance of tools	2,000	„
	4,700	„
The cost of oil pumps, tanks, and sundry appliances is given at	900	„

The cost of a complete set of boring apparatus, including "fishing tools," is about 790 dollars for a 5-inch to 6-inch hole, and reckoning one-third the value of the plant—boiler, machine, tubing, &c.—the actual cost of boring a 500-yard hole amounts to 6½ dollars the mètre, or 8*s.* 5*d.* per foot (the dollar being taken at 4*s.* 2*d.*). Wages are taken at 4 dollars.

The Author describes the class of pumps put in the hole, and concludes by stating that, without entering into comparative advantages of wire and hempen rope for boring, the latter in the water filled hole, appears better adapted for the quick working and heavy blow owing to less drag on change of velocity, and that it possesses the very considerable advantage of winding round small rolls, while the power required is considerably less in deep holes.

A. S.

The Turrettini Rock Borer.

(Giornale del Genio civile, vol. xv., pp. 399–405.)

The perforator or rock drill of Signor Turrettini differs from those already known in the distribution, and in the automatic advance and withdrawal, of the percussive apparatus.

The reciprocating movement of the piston is the effect of the difference of pressure exerted on its anterior and posterior surface. For the automatic advance and retreat the reaction produced by the compressed air is utilised. If the cylinder could move freely on its guides, it would have a tendency to move in the opposite direction to the piston. If, therefore, at a given moment (as at that immediately after the delivery of the blow of the cutter) the cylinder be allowed so to move, the whole apparatus will make a slight movement of advance towards the face of the rock. If, on the contrary, the cylinder be set free at the moment when the cutter commences its forward movement, the latter, wanting its due resistance, will only move slightly in advance, and the cylinder will impart to the entire apparatus a backward movement.

The advance toward the rock is made only when it is proper to bring the machine closer, and this is effected with much regularity. Details of the working parts, which would not be intelligible without the accompanying drawings, are given. The drill is said to deliver from six hundred to eight hundred blows per minute, and to consume 53 cubic feet of air compressed to the tension of 5 atmospheres. F. R. C.

Brandt's Rock-boring Machine. By F. Rziha.

(Wochenschrift des Oest. Ingenieur- und Architekten-Vereines, vol. ii., pp. 231–234.)

The Author, whose work on tunnelling is the acknowledged text-book on the subject in Germany, gives a brief description of this machine, invented by Herr Brandt, an engineer employed for several years at the St. Gothard works.

The inventor considers compressed air an unsatisfactory means of transmitting power, and substitutes for it hydraulic pressure. The machine consists of a hollow cylindrical steel drill with a toothed edge, which is pressed into the rock by a hydraulic press, and then turned round; the teeth tear and grind the rock away, and thus form a cylindrical aperture. It might be supposed that this violent tearing and grinding would soon destroy the teeth, but experience shows that the wear and tear is much less than in the case of percussive action.

The cylindrical drill is 3·1 inches in outside diameter, the metal being $\frac{2}{25}$-inch thick; it has five teeth, and bores out a hole of $3\frac{1}{4}$ inches diameter; the core breaks out at once, and is

removed by the pressure of the water which is passed through the drill. The pressure applied, about 7 tons, suffices to grind the hardest stone. The penetration of the drill is steady and constant, being always in due proportion to its revolutions. The power required to turn the drill is almost the same as that required to press it in. The machine itself is simple. The drill is attached to the piston of a hydraulic press; this piston revolves by means of a continuous worm which runs in a toothed wheel encircling the piston. The worm is moved by two small water engines. The pressure and the revolving apparatus can be fed separately, which was necessary since the nature of different rocks demands different proportions of speed and force between simple pressure and revolution. The machine is attached to a frame on two tubular legs, each of which is also supplied with a hydraulic piston to press against the floor and side of the drift or tunnel and give an absolutely immovable bearing. The water is led to the work through wrought-iron pipes with a pressure of 1,200 to 1,300 lbs. per square inch. Each drill requires only about 12 to 13 HP., even at a distance of 900 yards from the face. The consumption of water per drill and per hour is 66 cubic feet. This machine has been applied to boring the Sonnenstein tunnel on the railway between Gmunden and Ischl. With one machine of 12½ HP., and only two or three men, an average progress of 7 feet 6 inches per day was made, the cross section being nearly 70 square feet, and the rock a very hard dolomite full of quartz. Although this was the first time the drill had been tested in practice, it attained 13 feet per day as a maximum in the first month, while the highest figure reached by hand labour with treble sets of men had been 3 feet 3 inches. The plant required was very small. For each machine (one worked at each face of the tunnel) there is a pump, an accumulator, and ventilator, contained in a wooden hut at the entrance. The only repairs necessary were the grinding (setting) of the saw-teeth, although the same drill often bored several yards without being shifted. The speed varies from ¾ inch to 3 inches per minute, and it may be estimated that about thirty-five minutes are required to make a hole 5 feet deep. The two drifts met on the 11th of August, 1877, and the machines are now at work completing the tunnel, which is 1,560 yards long, and was commenced in May 1876.

The Author considers that Brandt's machine possesses five advantages with which no percussive boring apparatus can compete, viz.: (*a*) the quickness of the work; (*b*) its steady continuity; (*c*) the diminished power required; (*d*) the simplicity of the plant and of the working machinery; (*e*) the cheapness of the work, on account of the size of the holes, which enable much larger charges to be used and a greater effect to be produced. He also considers that it is far more certain and reliable than the diamond rock-boring machine, and applicable in many places where the diamond drill is not.

E. D'A.

Boring Machines in Prussia.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., pp. 224–249.)

In an official enumeration of recent improvements and inventions in mining, and classified under the head of "Winning," the various boring machines in use during 1876 are noticed. The following particulars may be useful.

Steel Drills.—After mentioning the experiences which have determined the fact of bar-steel drills being more economical than the ordinary "steeled" ones, some details of experiments conducted with steel drills—made of so-called Phœnix steel by the Martin process—are given.

First trial (with ordinary square chisels).—The drills were 24-inch, 33-inch, and 45-inch; number used, 24; thickness of steel (octagonal), 0·86 inch.

Weight of drills before trial	117·73 lbs.
„ after „	113·65 „
Actual loss in boring aggregate length of 19 yards .	4·08 „
Time required to bore said length was	2,688 minutes.
„ „ one yard . . . . . =	140·1 „
Sharpenings required per yard . . . . . =	3·77
Cost per yard—	
Loss of steel = 0·213 lb. at 5*d.* . . . =	1·065
Labour = 140 minutes at 0·1*d.* . . =	14·000
Sharpening = 3·77 at 1*d.* . . . . =	3·770
	18·835 or 1*s.* 6·835*d.*

Second trial (with crescent-shaped chisels).—This proved the loss in boring 12½ yards to be 1·907 lb.; the time required in boring 1 yard, 190 minutes, and the sharpenings per yard were 1·88. Calculated as above the cost amounted to 1*s.* 8·6*d.*

Mechanical Boring.—No actual data are given respecting hand boring machines, but the general conclusion must be drawn that their application has proved more unfavourable than ordinary hand labour. Of the boring machines, the Jellinghaus-Rosenkranz is mentioned as having proved fairly successful, but special prominence is only given to the Beaumont and Dubois-François borers. At the Matilda mine in Upper Silesia, where the latter machine was subsequently employed, the Italian miners had driven, on the average, 37·7 feet per month, in a gallery 6·5 feet by 5·2 feet, through sandstone and conglomerate, and the cost per lineal mètre, including carriage of debris to surface, smithy charges and

blasting material, amounted to 168·2*s.* (or 51*s.* 6*d.* per lineal foot), of which 18·38*s.* were for the last alone.

When the machine came into operation the size of the gallery was enlarged to 7·2 feet by 7·2 feet, and the cost per lineal mètre was gradually reduced from 320·9*s.* in February to 70*s.* in December. To these costs must be added the coal used for compressing air, 5·49*s.*; interest and redemption of capital, reckoned at 20*s.*; so that, taking the last two months, the cost amounted to 95·49*s.*, as against 162·2*s.*, which was the previous cost of hand labour.

The cylinder of this machine was 3½ inches in diameter, and the pressure varied from 3½ to 4 atmospheres; less than 3 atmospheres was found to be insufficient for an effective blow. A machine constructed in smaller proportions was found practically useless.

In the Westphalian district a gallery has been rapidly driven by employment of Beaumont's machine. While the monthly progress by hand labour had previously amounted to not more than 32·8 feet in sandstone, and 65·6 feet in shale, there were driven by the above borer 230 feet (134 feet in sandstone, 10 feet in coal, and 86 feet in shale); 360 feet and 338 feet, respectively, in three months; or a total (reckoning coal as shale) of 513 feet in sandstone and 415 feet in shale. The flow of water, amounting to 90 gallons during the last month, was, to some extent, an obstacle to progress. The cost of labour in driving and conveying debris to the pit-bottom amounted in round figures to 260*s.*, while the previous cost by hand labour was, on the average, 65*s.* per mètre, or one-fourth less; against this extra cost, however, must be considered the rapid advance, nearly eight times that effected by hand labour.

Results of boring, at the bottom of the Albert pit in the Saarbrück district, with the diamond borer, are also given. The first borehole was put down, with a ring-set crown, to a depth of 167·872 feet, in eighteen shifts, or 91·45 hours of actual boring, equal to a progress of 1·83 foot per hour; at this depth, owing to the wearing of the crown, the hole was so reduced that new crowns would not follow. A second hole was then started with a "full borer," and reached a depth of 87 feet, in sixteen shifts, or seventy-two hours of actual boring, equal to a progress of 1·2 foot per hour. At this depth a ring-set crown was again employed, and a depth of 361 feet reached in seventy-one shifts, the progress during the time of actual boring being 2 feet per hour.

The following remarks are made:—

Previous observations, to the effect that a diameter of 1·18 inch (30 millimètres) is insufficient for a continuous core, are substantiated, and as an instance it is mentioned that the aggregate length of cores extracted from the No. 1 hole did not amount to more than one-third of the total depth, being (in lengths of 6½ feet) in pieces from 4·6 feet to only 6 inches, while, from the coal seams passed through, only inconsiderable fragments were

obtained, so that their thickness could only be approximately ascertained by the colour of the clearing-out water.

The loosening of the diamonds is attributed more to the difference in hardness between them and steel than to bad setting, and a brief explanation is given of this loosening action. It was considered advisable in the execution of the bore-holes in question to limit the use of a crown to a length of 66 feet of hole, and by so doing it is thought that the loss of diamonds is materially diminished.

It was shown that such different strata as were met with (in the coal measures) made little difference to the progress: thus the rates of boring in the first 90 feet of No. 1 bore-hole were—

In shale	38·15	inches	per hour.
„ sandstone	40·34	„	„
„ conglomerate	44·10	„	„

While this result is mainly attributable to the excessive hardness of the diamonds, it is also clear that considerable advantage results from the facility with which extra power can be imparted. This constitutes an important difference between rotative and percussive boring. A table is given showing the progress under different pressures, and another contains the comparative results under various pressures, combined with increasing velocities. The first of these shows that while the advance per hour was 40·2 inches under a pressure of 2,090 lbs., it decreased to 12·9 inches when the pressure was reduced to 660 lbs.; the second shows that from an advance per minute of 1 inch under pressure of 1,276 lbs. and 180 revolutions, an increase is made to $2\frac{3}{4}$ inches under pressure of 2,244 lbs. and 244 revolutions.

The disadvantage of the "full borer," as compared with the "ring-set," or hollow borer, is determined by a calculation based upon their progress being directly proportional to the mean rotation radius, and inversely to the amount of cutting surface. This shows that, for the crown bits used at the Albert pit, the progress under similar conditions should be 2·87 times more rapid in the case of the ring crown. The observed difference was 2·44. This proportion varies with different-sized holes, and the saving of time, by more continual work, must be considered in favour of the full borer.

A. S.

On a Twelve-mètre Guibal Fan. By L. LAGUESSE.

(Revue universelle des Mines, new series, vol. ii., pp. 59–73.)

The Coal Mining Company of Crachet-Picquery, at Frameries, has lately made an important series of experiments with a Guibal fan of 12 mètres diameter (39 feet 5 inches). The results show

that the apprehensions generally entertained with regard to fans of large size are unfounded, and also that compared with such fans any form of piston or constant-volume ventilator loses its one apparent advantage over centrifugal ventilators, viz., the production of a better vacuum. The occasion for this fan arose from the Company finding it necessary to double the output from one of its mines in order to work the upper and lower seams at the same time. This mine had three shafts, one of which was fitted with a furnace, and another with a Guibal fan 23 feet in diameter. The Company decided on sinking a fourth shaft, 13·1 feet in internal diameter, but until this could be completed (a time of more than two years), it was necessary to provide apparatus for drawing an additional volume of 35 to 40 cubic mètres (46 to 52 cubic yards) per second through the existing workings. A Lemielle ventilator, 23 feet high and 16½ feet in diameter, was tried for this purpose; but experiments showed that, at an extra speed of 25 revolutions, the quantity discharged was only 25·384 cubic mètres per second, with a vacuum represented by 0·143 mètre of water (5·6 inches); and that in spite of all possible care in construction and maintenance the ordinary speed of working could not be taken at more than 18 revolutions, which gave a volume of 19·304 cubic mètres, with a vacuum of 0·098 mètre (3·9 inches). The addition of a second Lemielle ventilator would of course have given the discharge required; but this was decided against, because experience proved that with the Lemielle ventilator frequent stoppages cannot be avoided from accidents occurring either to the vanes themselves or to the rods which actuate them. It was also to be remembered that in two years a large new shaft would be available for the return of air; and the main reason for requiring at the moment a very high vacuum was, that the existing return shafts were of small section, and a great difference of pressure was therefore necessary to force a sufficient quantity of air through them. This was shown by experiments made in the mine itself. The result of the new shaft would thus be to improve the "temperament" of the mine (viz., the ratio of the square of the discharge to the corresponding height of water column). The question which form of ventilator would answer best with this improved temperament had been solved at a neighbouring colliery, where a Lemielle ventilator, 16½ feet high, 23 feet in diameter, and a Guibal fan, 6·6 feet long, 29½ feet in diameter, were in connection with the same shaft; these were both worked with a connection between the shaft and the surface alternately closed and open, so as to give a greater resistance in the first case than in the second. In both cases the Lemielle was worked at 12·77 revolutions, and the Guibal at 59 revolutions per minute. With both ventilators the discharge rose in the second case; but in the Lemielle it was only from 27·041 cubic mètres to 28·036 cubic mètres, while with the Guibal it was from 27·090 cubic mètres to 30·030 cubic mètres. This advantage on the side of centrifugal ventilators, combined with their less liability to accident and

greater facility of maintenance, decided the Company to give them the preference over those of constant volume.

The principle of the fan being thus adopted, and the Guibal selected as the best existing type, it remained to consider whether a small fan at high speed or a larger fan at more moderate speed would best answer the purpose. Two methods have been used in the district for working fans up to a high speed. The first is by belts and pulleys of different dimensions, which acts well for volumes of 15 to 20 cubic mètres of air; but beyond this the great size required for the pulleys and the loss of power in the belts render the method inapplicable. The second is by toothed wheels and pinions driven by engines provided with variable expansion gear; but with this system it has been found impossible to prevent constant shocks which endanger the teeth; these latter also wear unequally, those which act at the time of full pressure lasting a much shorter time than the others. From these considerations it was resolved to have a fan of large diameter and moderate speed. At this time the Brotherhood three-cylinder engine was attracting much attention; and as its simplicity and speed of working appeared to promise favourable results, one was fitted to a Guibal fan, 23 feet in diameter, which was available for the purpose. The engine was worked for nearly a year, but finally abandoned, as it was found impossible, with any of the means of lubrication employed, to prevent heating and seizing of the moving parts in the cylinders. A horizontal "Meyer" expansion engine was ultimately put down for the new fan, having a diameter of 0·68 mètre (26·6 inches), and a stroke of 0·85 mètre (33·5 inches). Accidents with large fans have generally been due either to vibrations of the shaft or to defective keying of the arm centres. In this case a forged shaft of 0·32 mètre (13 inches) was used, which proved perfectly rigid; and besides the ordinary keying, a cast-iron boss was placed on the shaft between the centres, and secured to it by a spiral row of powerful binding screws. In the construction of the fan itself, the masonry roof, and the wooden casing, every precaution was taken to guard against the possibility of accident.

The final specification was that the fan should be 12 mètres in diameter (39 feet 5 inches), 2½ mètres wide (8 feet 2 inches), and should be capable of drawing from the mine 40 cubic mètres (52½ cubic yards) of air per second, with a vacuum of 200 millimètres (7⅞ inches) of water, at a speed of 80 revolutions per minute, and with a steam pressure of 3 atmospheres. Experiments were made by two independent engineers to ascertain whether the fan, as erected, fulfilled these conditions. These were made with the mine in its ordinary state of working. The velocity of the air was measured in the passage leading from the shaft to the fan (the section of which was 57·8 square feet), by means of a Biram's anemometer, carefully verified beforehand. The fan was to have been tried at three different speeds, 50, 60, and 80 revolutions per minute; but the steam supplied was insufficient to produce more than a speed

varying from 76 to 79 revolutions per minute, the mean being 77·5. The results are given below:—

Revolutions.	Mean Velocity of Air.	Volume of Air.	Depression of Water Column.
Per minute.	Feet per second.	Cubic yards per second.	Inches.
50	18·9	40·218	3·27
60	22·2	47·368	4·65
77·5 (mean)	27·13	57·748	7·44

It will be seen that the fan had thus more than fulfilled the conditions as to quantity of air extracted, while its construction and working were reported as being in every respect satisfactory. Indicator diagrams of the engine were taken at the same time, with a view of ascertaining the useful effect, but it was found that at the higher speed these were a failure. For the speeds of 50 and 60 revolutions they gave a useful effect (or ratio between the power developed in the air passage and in the cylinder) of 0·5385 and 0·5551 respectively. Observations were also made of the air-pressure within the chimney of the fan, by which the air escapes. For this purpose the tube of a manometer was passed through the brickwork, and gradually pushed farther and farther from the wall, so as to measure the depression of the water column for each part of the chimney. This was done at three places, the heights of which above the actual outlet of the fan were 4 inches, 11·2 feet, and 27·3 feet respectively. With a depression in the fan of 3·5 inches, the depression at the lowest place varied from 0·4 inch close to the wall to 1·85 inch at the centre; giving a mean depression of 0·93 inch, or a ratio of 0·26 between the depression in the chimney and in the fan. At the second place, the variation was from 0·04 inch at the wall to 0·48 inch at 4·3 feet from it. At the highest place, the variation was from 0·04 inch at the wall to 0·22 inch at 2 feet from it. Similar results were obtained with depressions in the fan of 4·6 inches and 5·9 inches. On the whole the experiments showed that the velocity throughout the area of the chimney was tolerably uniform, and that consequently there could be no fear of any re-entering currents.

W. R. B.

On Ventilating Shafts in Coal Stores. By H. Henning.

(Journal für Gasbeleuchtung, vol. xx., pp. 518–520.)

Messrs. Abel and Percy, in the report upon ventilation and spontaneous combustion in coal,[1] held that ventilation on board ship

[1] "It does not appear practicable, therefore, to apply ventilation with any prospect of guarding against the accumulation of heat in some portion of a cargo of

was impossible, and that in stores ventilating shafts were not only useless, but dangerous. The following facts seem to point to a different conclusion.

The Author had to erect (at Danzig) a coal-shed of considerable size. On two previous occasions extensive fires occurred in which 1,000 tons of Silesian coal, and in another instance 2,800 tons of English coal were partly reduced to coke and partly consumed. Observations made at the time showed that the heated air could leap over distances of 10, 20, and 25 feet without any perceptible cause. These facts induced the Author to introduce ventilating shafts in the new sheds, in spite of the various opinions against their application. Two thousand tons of very damp English coal were put into the new shed. The ventilating shafts, in the absence of any data as to their distance, were placed at random, 25 feet apart in one direction and 12 feet in the other, and communicated at the bottom with underground channels.

The amount of moisture in the coal was about 2½ per cent.; and about a fortnight later the whole shed was filled with steam, and the air in the ventilators had risen to 95° and 113° Fahr. The shafts were provided with valves, so as either to admit or exclude the external air. These were immediately opened, upon which there was so rapid an evolution of steam, that the next day the evaporation had nearly ceased, and after eight days no more vapour was visible. The coals were then removed, and it was found, that in the direction of the 12-feet distance they were perfectly cold, while in the 25-feet direction the middle portion was warm for a length of about 12½ feet. This was a clear proof that the distance of 25 feet was too great. The height to which the coal was stored was 20 feet.

From these facts the Author concludes that ventilating shafts, placed at distances equal to one-half the height to which the coal is stacked, will under all circumstances have a good effect; and if a thermometer is inserted into the air shafts, a sure test of the condition of the coal is constantly at hand.

J. G. H.

On Turbines with Partial Distribution. By PROF. RICHELMY.

(L' Ingegneria civile e le Arti industriali, vol. ii., pp. 64, 115, 135, 155.)

An essential difference ought to be maintained between the arrangement of turbines with partial distribution, and that of turbines with total distribution. For the latter, the space com-

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coal. Indeed, a period would be reached when the development of heat would be most seriously promoted by ventilation, some time before actual ignition demanded the total exclusion of fresh air."—Paper by F. A. Abel, Esq., F.R.S., and J. Percy, Esq., M.D., F.R.S., in the Report on the Spontaneous Combustion of Coal in Ships, 1876, p. xxvi.

prised between the supply chamber and the motor should generally have no contact with the atmosphere; while, with those for partial distribution, the atmosphere should always penetrate into that space. If, in fact, this do not take place, the passages constituting the motor, comprised between vane and vane, will be subject to a rapid and injurious variation in the pressure against the upper face. When the passage is in front of one mouth of the supply chamber, that pressure will correspond to the head in the supply chamber: when the passage passes in front of the closed part of the supply chamber, the pressure will rapidly cease.

Presupposing the free circulation of the air, between the supply chamber and the motor, the theory becomes very simple. The water in the supply chamber moves as in a closed pipe, the two extremities of which are subjected to atmospheric pressure only. The head, and the sum of the orifices are known; whence it becomes easy to calculate the theoretical discharge. Some loss may occur in the head by friction and by reason of the passages between successive sections being appreciably different in area. Many experiments made with a view to discover the actual amount of all these losses have induced the Author to estimate them at between five hundredths and eight hundredths of the head, according to circumstances. Nevertheless, the effective discharge being somewhere between ninety-two hundredths and ninety-five hundredths of the theoretical, and the efflux taking place from the orifices of the supply chamber without contraction, the diminution ought necessarily to be attributed to a lesser velocity of efflux, due no longer to the head, but only to this multiplied by $(0{\cdot}92)^2$ or $(0{\cdot}95)^2$, or by a number intermediate between these two. The head upon the discharging orifices from the supply chamber, for many wheels, is almost equal to the fall; whence, for all these turbines, from 10 to 15 per cent. of the energy of the stream of water is lost by friction, by bends in the pipes and passages, and by the sudden changes of section which precede the outflow from the supply chamber. Then, when, having left this first organ of the apparatus, the water is ready to enter into the motor, it is not difficult to estimate the relative velocity with which it proceeds to do so. Resolving the absolute velocity of the efflux into two components, the first of which is the velocity of rotation of the parts of the motor where the water is introduced, the second component is the relative velocity sought. The water, being left with this velocity inside the spaces comprised between the one and the other of two consecutive vanes, will be able to preserve it, or will be obliged to change it. This latter is the case which under a certain aspect may be said to be more frequent. Then the relative velocity, which the water must take, is determined by means of the law of continuity, and has a direction which is fixed by the inclination of the vane to the circumference of the wheel. There are, then, two different relative velocities, the second of which is altogether independent of the intensity of the rotary velocity of the motor; but the first of which depends on it: whence, in order

to coincide with the other, it is necessary that the angular velocity of the wheel should have a certain value; but if that cannot be established or maintained, the coincidence cannot be found. For this reason the second case is said to be more frequent than the first. Then in the passage of the water from the one to the other of these two relative velocities, consequent on sudden change, there will be a loss of work.

When the water begins to pass through the motor, every liquid molecule is endowed with double velocity, the relative velocity with which it flowed into the passages comprised between vane and vane, and the velocity which it has in common with the wheel which carries it. The relative velocity of the efflux is found by applying to the water passing through the motor the theorem of work, and remembering that when the motion occurs in a horizontal direction, it will be convenient to take into consideration the centrifugal force as well. Finally compounding this relative velocity of the efflux with that of translation that the water will have in common with the parts of the wheel from which it flows, there will be obtained the absolute velocity with which the water leaves the wheel. From all that has been said, so far, it will be seen that, if

Q = the volume of available water;
G = the specific weight of the water;
H = the total height of the fall, which is then divided into two parts, h_1 the part above the wheel, and h_2 the height from which the water descends while it is in the wheel (for centrifugal wheels $h_2 = 0$);
V_0 = the velocity of the efflux from the supply chamber;
W = the velocity lost by collision in the entrance of the water into the motor;
V_1 = the absolute velocity with which the motor is left;
L_m = the motive work absorbed by the wheel;

there are obtained accordingly the equations:

$$\frac{V_0^2}{2g} = h_1(1 - \mu^2);$$

$$L_m = GQ\left(\frac{V_0^2}{2g} + h_2 - \frac{W^2}{2g} - \frac{V_1^2}{2g}\right);$$

representing in the first of these equations by μ^2 that fraction of h_1 which is lost during the time that the water still runs in the supply chamber, a fraction which lies somewhere between 0·10 and 0·15. Thus the principal object to be aimed at, in order to arrive at a useful result, will be to minimise μ, W and V_1. The values of W and V_1 can easily be determined, in every actual case, in functions of the dimensions and arrangements of the turbine, as well as of the angular velocity of rotation ω. In endeavouring to determine that value of ω for which $L_m = 0$, the greatest angular velocity which the turbine can attain will be found when it has no

work to do. If on the other hand it be supposed that L_m is a maximum, one will fall upon the angular velocity for which the useful effect becomes greatest. The researches thus indicated are neither impossible, nor of any length. They lead always to equations of higher degrees which it is convenient to resolve by approximation.

These theories are then compared with the results obtained in forty-six experiments made at the hydraulic establishment of the School of Engineering at Turin. It is shown how, in certain points, the coincidence of these results with theory may be regarded as nearly perfect; while in others plausible reason can be assigned for the discrepancy.

From the preceding results there are deduced the following practical rules for the construction of turbines. For turbines of parallel flow, the fall H is divided into two parts, h_1 and h_2, and the Author believes it is always better to exceed in h_1; the height of $2\frac{1}{2}$ decimètres, at the most, sufficing for the h_2. Thus the greater part of the fall acts on the supply chamber. With respect to the supply chamber the following are the principal instructions:—

(1) In all the passages which lead to the distributing passages, it is necessary to avoid too narrow sections, sudden bends, and rapid changes in the area of the section.

(2) For the distributing passages proper, the entrance should be as far as possible funnel-shaped, and with a vertical direction; the curvature should be gradual in order that at the point of discharge they may have the right direction. Their curvature is of little consequence, so long as it has the desired continuity; 1 decimètre to 2 decimètres will suffice for their vertical height.

(3) The size of the passages in terms of the radius, taken where it is narrowest, *i.e.* at the orifice of exit, should not exceed the fifth of the radius, and may be less. Circumferentially they should occupy an arc less than half of this circumference—this also upon the upper face, where, in order to give them the form of a funnel, they are more extended. This condition, and the necessity to give free vent to all the available water, give a lower limit for the radius of the turbine.

The total arc occupied by the passages may be in one, or can be divided into two or three parts, symmetrically disposed with reference to the centre. The general practice is to divide it into two parts diametrically opposite. Such an arrangement, in fact, balances the wheel better: restricting the distributing orifices to one place, the useful effect is greater theoretically, and also practically, if the experimental results of Girard are to be relied on.

With regard to the motor, it is to be noted that the width, in the direction of the radius of the circular crown, where the water enters, ought to be that of the distributing zone, increased, if necessary, by a small quantity, in order to avoid the danger of any of the water being lost. The distance between the vanes should be the same as that between the guide-blades of the supply

chamber. The other dimensions will be more simply expressed algebraically. In addition then to the symbols already adopted, let

R = the mean radius of the wheel, measured from the centre to the middle of the crown;
a = the length of the arc (less than π) of the circumference occupied by the distributing passages;
δ_0 = the width in terms of the radius of the crown, measured at the top of the wheel, and let $\delta_0 < \frac{1}{2} R$;
δ_1 = the same width taken at the inferior extremity of the wheel;
ϕ = the angle with the horizontal plane, and therefore with the circumference $2 \pi R$ of the last element of the supply chamber, taken at the centre of the directrix;
θ_0 = the analogous angle for the first (higher) element of the vane of the wheel;
θ_1 = the analogous angle for the lower element;

let further

v_0 = the relative velocity with which the water ought to enter into the wheel;
v_1 = the relative velocity with which it ought to leave it;
ω = the angular velocity of the motor;

in addition to the equation already determined,

$$V_0 = \sqrt{2 g h_1 (1 - \mu^2)},$$

the following ought to be satisfied:—

$$a R \delta_0 V_0 \sin \phi = Q,$$
$$V_0 \sin \phi = v_0 \sin \theta_0,$$
$$v_0^2 = V_0^2 + R^2 \omega^2 - 2 V_0 R \omega \cos \phi,$$
$$v_1^2 = v_0^2 + 2 g k,$$
$$v_1 \cos \theta_1 = R \omega.$$

Further if, in the outflow of the water from the wheel, a loss of head is admitted, represented by k, it should then be

$$v_1^2 \sin^2 \theta_1 = 2 g k.$$

It then remains to satisfy the equation

$$V_0 \sin \phi = \frac{\delta_1}{\delta_0} v_1 \sin \theta_1.$$

For centrifugal turbines the rules have much analogy with those given for parallel-flow turbines. In the pipes leading to the distributor passages, it is necessary to avoid all causes diminishing the useful height of the fall, such as friction, and sensible

changes in the direction, or in the area of the section; also for this it will be useful to take care that the entrance into those passages be made funnel-shaped, and that the curvature of the same be continuous. What has been said about the supply chamber should be repeated for the motor, that many directions analogous to those given for the other species of turbine are applicable. Nevertheless the quantities to be determined are different. In the motor there are two radii, the internal R_0 and the external R_1; there are two heights of the wheel, the interior b_0 and the exterior b_1. α = the extent of the arc of the supply chamber discharging the water; ϕ, θ_0, θ_1, v_0, v_1, retain the previous significations. k represents the part of the fall which is permitted to be lost, in order to have a certain absolute velocity to the water that leaves the wheel. With these quantities the seven following equations ought to be satisfied:—

$$V^2 = 2g\left(H - \frac{v_0}{2}\right),$$

$$\alpha R_0 b_0 \sin\phi V_0 = Q,$$

$$V_0 \sin\phi = v_0 \sin\theta_0,$$

$$v_1^2 \sin^2\theta_1 = 2gk,$$

$$v_1 \cos\theta_1 = R_1\omega,$$

$$v_1^2 = v_0^2 + (R_1^2 - R_0^2)\omega^2,$$

$$v_0^2 = V_0^2 + R_0^2\omega^2 - 2V_0 R_0 \omega \cos\phi,$$

To which it will be useful, but not indispensable, to add

$$V_0 \sin\phi = \frac{b_1 R_1}{b_0 R_0} v_1 \sin\theta_1.$$

Bearing in mind then that the quantities which may be regarded as available in the construction of the turbine are eight—*i.e.* the two radii R_0 and R_1, the two heights b_0 and b_1, the three angles ϕ, θ_0, and θ_1, and the extent of arc α, and that in solving the equations there ought to be added the three velocities which remain unknown, V_0, v_0, and v_1, there will be eleven indeterminates, and only eight equations. It is then possible to dispose arbitrarily of three. But it must not altogether be forgotten that there are limits within which some of these quantities ought to be confined; thus, for the sake of example, the first of the eight equations shows that it is better to make b_0 small, rather than too great; but it must be well understood that this diminution ought never to go lower than 8 centimètres. It will be more simple to make b_1 equal to b_0, or rather larger; but if the hypothesis $b_1 = b_0$ should lead to a radius R_1 too great, it will be useful to take $b_1 > b_0$. Lastly, the extent of arc α must always be maintained less than π, especially in this second species of turbines, if the distributing passages are to be kept funnel-shaped. Reflecting that the radius of entrance into those passages is less than R_0, α ought to be much less

than π; but if this should lead to radii too great, this condition may be surrendered at the cost of having to study another manner of closing for the distributors. From turbines made according to the preceding instructions, it seems to Professor Richelmy that one may always hope for a co-efficient of return superior to 80 per cent.

C. C.

Theoretical Investigation of the Variable Motion of Fluids, and its Application to the Propagation of the Floods of Rivers.

By M. KLEITZ.

(Annales des Ponts et Chaussées, vol. xiv., pp. 133–193, 1 pl.)

The Author's object is to furnish a theory of the motion of fluids when the height of their surface is constantly altering, with a special view of investigating the motion of floods in rivers.

Taking first the case of an infinitesimal particle, $\delta\omega\, ds$, of the fluid, the equation of equilibrium is

$$\delta\omega\, ds\left\{g_s - \frac{1}{\rho}\frac{dP}{ds} - \left(\frac{dv}{dt} + v\frac{dv}{ds}\right) + f_s\right\} = 0 \quad . \quad . \quad (1)$$

where ρ is the density of the fluid; g_s the component of gravity along the axis designated by s; P the mean pressure; f_s the molecular dynamic force.

Considering next a portion of the current contained between two sections w and w', the equation is

$$\frac{dz}{ds} = \frac{1}{g}\left(\frac{du}{dt} + u\frac{du}{ds}\right) + \phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where z represents the ordinates of the surface lines of the sections w and w'. To the above equation must be added the equation expressing the condition of continuity of the fluid,

$$\frac{dq}{ds} + \frac{d\omega}{dt} = 0.$$

If the distance between the two sections is finite, equation (2) becomes

$$\frac{dz}{ds} = \frac{1}{g}\left(\frac{du}{dt} - \frac{u}{\omega}\frac{d\omega}{dt}\right) - \frac{1}{g}\frac{u^2}{\omega}\frac{d\omega}{ds} + \phi.$$

It is assumed, for the sake of simplicity, that the river is confined to a single channel, and that the flood rises gradually to a maximum, and then gradually sinks to its normal level. A longitudinal section of the surface of a river in flood is liable to irregularities, owing to differences in size of the river bed;

and a better representation of the flood is obtained by taking the discharges which occur in the different sections as ordinates of the longitudinal section of the flood.

The rate of propagation, w, of a discharge of flood waters is given by the equation

$$w = \frac{\frac{dq}{dt}}{\frac{d\omega}{dt}} = u + \frac{\omega \frac{du}{dt}}{\frac{d\omega}{dt}}.$$

The rate of propagation of a discharge, q, is distinct from the rate of flow, u, corresponding to the discharge, and depends on the rate of variation of the discharge in proportion to that of the section. A simple flood wave diminishes in height, increasing in length, as it proceeds down a portion of a river without a tributary coming in. The result of embanking a river, and thus reducing the reservoir area, is to increase the maximum flood discharge below. On examining the equation giving the value of w, it appears that w is greater than u at the beginning of the flood, when u is increasing; that w is equal to u when, $\frac{du}{dt}$ becoming nothing, u attains its maximum value; w next becomes less than u, and becomes nothing when q attains its maximum. The meaning of w becoming nothing is that the corresponding maximum discharge does not take place lower down. At that period the maximum discharge is taking place at some point above. The height of floods is kept down by the flooding of large contiguous plains; and the frequent formation in tributaries of secondary channels causes the maxima discharges to arrive at the main river at different periods. The increased height which floods attain at the present day is due in great measure, if not mainly, to the reduction everywhere of the area of inundation by raising the banks, or forming regular embankments.

The Author gives a number of formulæ relating to the propagation of floods, and discusses them in detail.

L. V. H.

The Discharge of Canals.[1] By Capt. Allan Cunningham, R.E.

(Professional Papers on Indian Engineering, 2nd series, vol. vi., pp. 286–299.)

In this Paper is embodied the experience gained by the Author in carrying out his important and well-known series of hydraulic experiments for the Indian Government. The immediate object of the publication is to secure uniformity in the system of discharge

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlviii., p. 322.

measurements. For small canals, the Author relies upon the researches of MM. Darcy and Bazin, upon which is based the appended table of variable co-efficients, for use in the ordinary formulæ for mean velocity of discharge.

r = Hydraulic mean depth in feet.
S = Fall of water surface in any distance divided by that distance.
v_0 = Maximum surface velocity in feet per second.
V = Mean velocity in feet per second.

TABLE I.

Values of C
for use in formula $V = C\sqrt{rS}$.

Hydraulic Mean Depth in Feet. r.	Value of C. Bed and Sides of Fine Plaster.	Bed and Sides of Cut Stone or Brickwork.	Bed and Sides Rubble or Boulder Masonry.	Bed and Sides of Earth.	General Value of C for use when $r > 20'$.
·5	135	110	72	36	Bed and sides of fine plaster $C = \sqrt{\left(1 + \frac{1}{r}\right)\left(10{\cdot}16 + \frac{1}{r}\right)}$
·75	139	116	81	42	Bed and sides of cut stone or brickwork, $C = \sqrt{\left(1 + \frac{1}{r}\right)\left(4{\cdot}354 + \frac{1}{r}\right)}$
1·0	141	118	87	48	Bed and sides of rubble or boulder masonry, $C = \sqrt{\left(1 + \frac{1}{r}\right)\left(1{\cdot}219 + \frac{1}{r}\right)}$
1·5	143	122	94	56	Bed and sides of earth, $C = \sqrt{\left(1 + \frac{1}{r}\right)\left(·2438 + \frac{1}{r}\right)}$
2·0	144	124	98	62	
2·5	145	126	101	67	
3·0	145	126	104	70	
3·5	146	127	105	73	
4·0	146	128	106	76	
4·5	146	128	107	78	
5·0	146	128	108	80	
5·5	146	129	109	82	
6·0	147	129	110	84	
6·5	147	129	110	85	
7·0	147	129	110	86	
7·5	147	129	111	87	
8·0	147	130	111	88	
8·5	147	130	112	89	
9·0	147	130	112	90	
9·5	147	130	112	90	
10·0	147	130	112	91	
11·0	147	130	113	92	
12·0	147	130	113	93	
13·0	147	130	113	94	
14·0	147	130	113	95	
15·0	147	130	114	96	
16·0	147	130	114	97	
17·0	147	130	114	97	
18·0	147	130	114	98	
19·0	147	130	114	98	
20·0	147	131	114	98	

TABLE II.

Values of c
for use in formula $V = c\,v_0$.

Hydraulic Mean Depth in Feet. r.	Value of c. Bed and Sides of Fine Plaster.	Bed and Sides of Cut Stone or Brickwork.	Bed and Sides Rubble or Boulder Masonry.	Bed and Sides of Earth.	General Value of c for use when $r > 20'$.
·5	·84	·81	·74	·58	$c = \frac{C}{C + 25{\cdot}3}$
·75	·84	·82	·76	·63	
1·0	·85	·82	·77	·65	
1·5	·85	·82	·78	·69	
2·0	·85	·83	·79	·71	
2·5	·85	·83	·79	·72	
3·0	·85	·83	·80	·73	
3·5	·85	·83	·80	·74	
4·0	·85	·83	·81	·75	
5·0	·85	·83	·81	·76	
6·0	·85	·84	·81	·77	
7·0	·85	·84	·81	·78	
8·0	·85	·84	·81	·78	
9·0	·85	·84	·82	·78	
10·0	·85	·84	·82	·78	
11·0	·85	·84	·82	·78	
12·0	·85	·84	·82	·79	
13·0	·85	·84	·82	·79	
14·0	·85	·84	·82	·79	
15·0	·85	·84	·82	·79	
16·0	·85	·84	·82	·79	
17·0	·85	·84	·82	·79	
18·0	·85	·84	·82	·79	
19·0	·85	·84	·82	·79	
20·0	·85	·84	·82	·80	

Table I. must necessarily be used in estimating the probable discharge of a contemplated canal, but if the canal be actually running, Table II. alone should be employed. In the latter case, Captain Cunningham's experience leads him to believe that at least twenty separate measurements should be made, and their arithmetic mean be taken as the "average value of the central surface-velocity" (v_0).

For large canals the Author would not rely on Table II., but would measure the "mean velocities" past a great number of verticals in the same cross section either with "velocity rods" or with a current meter. Experiments at Roorkee have established the fact that under proper conditions a rod reaching from the surface to nearly the bed affords a very fair measurement of the mean velocity in any plane. The rod used at Roorkee is simply a tube 1 inch in diameter, made of sheet tin; the lower portion, or loaded end, is formed round a short length of rod iron, the diameter of which, in fact, determines the diameter of the whole tube. The length of iron used is such that its weight almost submerges the tube to the depth desired, the fine adjustment being effected by the addition of small shot by experiment in still water. About 2 or 3 inches is left projecting out of the water, and the mouth sealed permanently with a disc of sheet tin. The whole is painted black, as a protection from the water. The Author describes in detail the mode of procedure which he has found most convenient in practical working with these rods, and concludes with a tabular form which he would be glad to have filled in and returned to him by all those engaged in hydraulic observations, so as to obtain thereby data for the verification of formulæ for mean velocities.

B. B

Properties common to Pipes, Canals, and Uniform Rivers.

By P. Boileau.

(Comptes rendus de l'Académie des Sciences, vol. lxxxv., p. 429–32.)

The history of the numerous researches undertaken since 1730 to determine the law of the resistance of the sides to the movement of translation of liquid currents is well known; but researches have yet to be made to obtain formulæ that engineers may use with perfect security, and some new considerations may be useful. The Author terms intensity the value of the resistance on the unit of area of the fluid surface in contact with the sides of currents of uniform régime, excepting where there are bends and bifurcations, the influence of which is a subject for special study. The Author first considers the old basis of evaluation. Let f be the intensity, w the velocity of the fluid surface, a and b numerical co-efficients,

and δ the density of the liquid. According to ideas that have been admitted to the present time,

$$f = \frac{a}{g}\delta\left(w^2 + \frac{b}{a}w\right) \quad . \quad . \quad . \quad . \quad (1)$$

Now R_1 designating the mean radius of the currents, one of the conditions of uniformity gives $f = \delta R_1 i$; on the other hand, by virtue of one of the theorems previously established by the Author,[1] the loss of head

$$i = K(V - w)^2 \, . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

V being the velocity of the principal current-thread, and K a factor which varies from one current to another, with the rugosity of the sides, the depth and width of the transverse liquid section, and even with the figure of the perimeter of that section, there can be put under a comparable form the expression (1)

$$f = K R_1 \delta [w^2 - 2(w - \tfrac{1}{2} V) V] \, . \quad (3)$$

It is to be seen that the factor of the function of the velocities—a factor that has been regarded as constant for the same fluid and the same rugosity of the sides—should vary besides with the geometric quantities previously cited. The divergence is greater still in what concerns the influence of the velocities; for, if in the expressions (1) and (3) for f both have a term proportional to w^2, the second term, instead of being in all cases additive and simply proportional to w, is more complex, and it may be subtractive, nil, or positive when the velocity is superior, equal, or inferior to half that of the principal thread. The old basis of the usual formulæ should therefore be abandoned. The formulæ prepared for practical requirements should be functions, not of w and of V, or of w only, but of the mean velocity U of the currents, and of the form

$$R_1 i = A U^2 + B U \quad . \quad . \quad . \quad . \quad (4)$$

which has been in use since Prony's time, and has served for the laying down of numerical tables resting on two hypotheses, namely, that Coulomb's formula is applicable to currents, and that the relation of U to w is constant, hypotheses which notably depart from the actual case. From a scientific point of view, this formula is then doubly inadmissible. As to the approximations which result from it in practice, these do not appear to be sufficiently accurate. Preferable to these is Prony's equation (4), the factors A and B having been empirically determined by Darcy, and

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 317.

depending only on the mean radius of the currents and on the rugosity of the sides. The Author remarks that this equation gives, U and i only varying, values of the ratio $\frac{U}{\sqrt{i}}$ that decrease when i increases, whilst the result of experiments which may be relied on shows a contrary law. Before expounding a new theory, the Author desires to point out the law of influence of intensity of the resistance of the sides upon the decrease of velocity. He has shown in the previous Paper that

$$V - v = (V - w)\,F(y) \quad . \quad . \quad . \quad (5)$$

v being the velocity of a liquid envelope of a uniform current, and y the distance of the principal thread from the inferior point of intersection of that envelope. Now, from that relation and from expression (3), or

$$f = K R_1 \delta (V - w)^2,$$

it results that

$$V - v = \frac{1}{\sqrt{K R_1 \delta}} \sqrt{f}\, F(y) \quad . \quad . \quad (6)$$

consequently, the influence of the resistance of the sides on the decrease of velocity of liquid envelopes, starting from the principal thread, is proportional to the square root of the intensity of that resistance.

P. H.

The Mississippi River Improvements.[1]

By Capt. J. B. Eads, M. Inst. C.E.

(Journal of the Franklin Institute, 3rd series, vol. lxxiv., pp. 209–216.)

The construction of jetties at the mouth of the Mississippi having given a depth, at low water, of 30 feet out to sea, whilst there was only 14 to 15 feet of water, in October 1876, over the shoal at the entrance to the South Pass, it became necessary to form a channel through the shoal. This object was effected by constructing piers, contracting the South Pass from its old funnel-shape into a uniform channel 850 feet wide; and by sinking mattress sills, 2 feet thick, 70 feet wide, and 3,000 feet long, across the entrances to the South-west Pass and the Pass à l'Outre, so as to reduce the entrances into these two larger passes, and increase the scouring action through the channel into the South Pass. A narrow cut was dredged through the shoal, and when the river

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvii., p. 369.

rose in February 1877 the scouring action commenced; 70,000 cubic yards of sand being removed in the first seven days of February, and 450,000 cubic yards before the summer.

The scour in the jetty channel below, which had been suspended by the diminished flow of water through the contracted channel over the shoal whilst the river was low at the close of 1876, commenced again in March. The scour takes place in the central channel away from the jetties. A slight deposit occurs at the lower end of the jetties; but out of 544,000 cubic yards scoured from between the jetties above station 80, only 77,300 cubic yards have been deposited at the sea end of the jetties, the rest having been carried out into the Gulf of Mexico. Between the 25th of April and the 12th of June the 22-feet channel between the jetties had been extended 2,200 feet, and enlarged from 200 feet to 300 feet in width.

The Gulf in front of the jetty channel has been found to have gradually increased in depth.

The works carried out have resulted, hitherto, in the formation of a channel between the jetties more than 200 feet wide, and not less than 20 feet in depth, where previously the depth was about 8 feet; and a channel across the shoal at the entrance to the South Pass over 400 feet in width, and nowhere less than 20 feet deep and 30 feet in the centre, where before the depth was about 15 feet.

L. V. H.

Wing Dams in the Mississippi. By E. P. North.

(Transactions of the American Society of Civil Engineers, vol. vi., pp. 268–276.)

Just below St. Cloud, on the Mississippi, are the so-called Thousand Islands, where the river is spread by a gravel bar into many channels, preventing the passage of boats at low water. A very limited sum of money was available for the improvement of this passage, and the Author describes in detail how it was expended.

Stone for the dams could not be procured for less than 9*s.* 4*d.* per cubic yard, but brushwood was plentiful. It was determined, therefore, to build the dams of fascines, secured by stakes and gravel or sand. The length of dam may be called 2,900 lineal feet, the average height 3·3 feet, the cubic contents 7,225 yards, and the cost 9*s.* 9*d.* per lineal foot, or say 4*s.* per cubic yard. About 34 per cent. of the cost was for gravel, 24 per cent. for stakes and the labour of driving them, and 42 per cent. for making and placing fascines. The fascines, varying in diameter from 9 to 18 inches, and in length from 15 to 22 feet, constituted about 38·5 per cent. of the bulk of the dam. One row was generally placed across the bottom parallel to the current, brush ends up stream, and staked. A single row was then placed lengthwise of the dam, about 3 feet

up stream from the butts, and staked through each bundle under it. Gravel was then filled in to cover the tips of the lower row and make a plane surface to the transverse fascines. The succeeding courses were placed parallel to the current, except where the dam was unusually high, when another transverse course was placed, care being taken to have at least one course parallel to the current when the dam was finished. On the completion of the fascine work, any projecting stakes were cut off nearly flush with the surface of the dam, and all was then covered with a coating of gravel, carried horizontally about 6 feet up the stream. It is stated that the dams as described have stood well, though from the severity of the winter (—39° Fahr.), the ice is generally 3 feet, and in some instances 4 feet thick. Certain breaches have occurred, but they are considered to be due to the log-drivers, and not to the action of the river.

B. B.

Training Works of the Lower Ganges Canal.

By MAJOR H. H. JONES, R.E.

(Professional Papers on Indian Engineering, 2nd series, vol. vi., pp. 278–286.)

These works are situated on the left bank of the Ganges, between Rajghat and Narora; the former being the place where the Oudh and Rohilkhand railway crosses the river, and the latter the site of the weir intended to turn its waters into the new canal called the Lower Ganges Canal. The objects of these works were, first, to straighten the course of the river, which before their construction was very crooked, and, secondly, to prevent the flood waters of the Ganges, when raised above their natural level by the construction of the weir, from finding an outlet over the low country on the left or eastern bank, and outflanking the weir altogether. The works consist of two parts: 1. An embankment running along the edge of the Khadir land, called the left embankment; and 2. A system of groynes placed at right angles to the lateral embankment and projecting into the river, serving to drive the stream over, and subsequently to keep it from returning to its former course and endangering the embankment. The right bank of the river is high and permanent, being composed chiefly of strong clay, and strengthened by beds of kankar. The left bank is low and composed of sand, the actual left bank of the Ganges valley being 12 to 14 miles to the eastward. Before the works were commenced in March 1873, the works of the railway, higher up, aided by a number of brushwood spurs, had improved the course of the stream, but it still formed a great loop between Rajghat and the village of Narora, and at the apex of the loop the bed of the river was 1½ mile east of the course desired. The works undertaken in 1873 consisted of a part of the left embankment from the rail-

way bank, and ¾ mile of embankment from the left flank of the Narora weir upwards; and groyne No. 1, besides a tree-spur, 1,200 feet in length, just below the Rajghat railway bridge. The embankment was thrown back 1,000 feet to the east of the left wing of the Narora weir, so as to keep it clear of heavy scour during floods, and the top of the bank was fixed 5 feet above the probable high-water mark of floods after the completion of the weir. The top width is 15 feet, with front and back slopes of ¼ and ½ respectively. The groyne was constructed with a top level the same as that of the embankment from which it springs, with a top width of 15 feet and both side slopes ½. Groyne No. 1 is 2,800 feet in length. The head of the groyne is round, formed of double lines of stakes, the spaces between being filled with block kankar alternating with fascines in beds 2 feet thick of each. In the next season the embankment was carried on to the site of groyne No. 2, and that groyne was constructed 2,800 feet in length with a head similar to that of groyne No. 1, and a tree-spur 800 feet long was attached to the head of No. 1 groyne. In the following floods there was a severe scour on No. 2 groyne, which had to be protected by fixing trees along the face, and by a small spur of stakes and brushwood run out up-stream. The action of these works caused the cold-weather stream to recede 3,600 feet from the groyne head. Next season No. 2 groyne was extended to 4,600 feet in length, a new head was made, and a tree-spur attached to it, and the main embankment was also extended to No. 3 groyne. These works, aided by gangs of men who were employed loosening the earth that required removal, caused the stream to run in a straight course over the line of the weir. In the season of 1875–76 the system of main groynes was completed by the construction of No. 3 groyne, in a way precisely similar to the others, and by throwing out two small groynes from the embankment near the left flank of the weir, to prevent any lateral scouring action on the left embankment during floods. The embankment was also completed in this season. It is intended to throw up some small sand groynes between the main ones, to accelerate the silting up of the bays between the main groynes, when it is considered that the embankment will be well protected against scour.

F. C. D.

Sutlej River-Training Works at Adamwahan. By E. B. MEDLEY.

(Professional Papers on Indian Engineering, 2nd series, vol. vi., pp. 193–215, 1 pl.)

A former report by Mr. Graham described the operations carried out up to September 1874; the present Paper gives a detailed account of the works executed since that period. These consist of the construction and repair of tree bunds during the cold season at low water; of the formation of 100 feet "net spurs," during

ordinary flood time, for straightening the course of the river during the higher floods; and, lastly, of the formation of "weed spurs" with fascines and brushwood, after the flood season, to stop encroachments in the banks, and to protect sand-banks required to be maintained for sinking wells.

Several new tree bunds have been constructed to protect the banks, to cause a silting-up of old channels, and to alter the direction of the scour. These bunds are made of trees and bushes, tied together with 8-inch, 5-inch, and 2½-inch rope, and weighted by nets filled with brick. The river tends constantly to assume a zig-zag course, cutting into the banks. An attempt has been made to check this by net spurs, the nets being 100 feet by 3 feet, with meshes 6 inches square, and having nets filled with bricks, and casks attached to them, but these operations have been only partially successful. The weed spurs were placed along the bank, about 2 or 3 chains apart, in a strong current at depths varying from 10 to 20 feet. It has been found that by placing the spurs obliquely to the bank, instead of at right angles, a better resistance is offered to encroachments. The trees and bushes having been nearly exhausted in the neighbourhood of the river bank, the cost of future works will be increased; unless, as the Author suggests, the Forest Department should plant trees on each bank, which in five years would be large enough to be formed into spurs.

The amount of work done from January 1874 to 31st August, 1875, was as follows:—

Tree bunds	36,162	lineal feet.
Weed spurs	10,595	„
Net spurs	17,880	„
Total	64,637	„

The cost amounted to 317,176 rupees, or a little less than 5 rupees per lineal foot. The net spurs were tried as an experiment, and their cost might be saved in future. By the close of the second season the cost had reached 325,000 rupees; but as some materials remained in hand, Col. Peile, R.E., estimates the yearly expenditure at 125,000 rupees, which may be increased hereafter if there should be a dearth of trees as already alluded to.

L. V. H.

On an Iron Steam Dredger at Hussum, Schleswig-Holstein.

By E. W. Matthiessen.

(Zeitschrift für Bauwesen, vol. xxvii., pp. 490–502.)

This dredger was employed in the harbour and river of Hussum, on the west coast of Schleswig, for the purpose of making and

maintaining a deep navigable channel for the maritime service between Hussum, the neighbouring islands, Hamburg, and England. In the upper part of the river there was a large deposit of clayey marsh ground, and in the lower part chiefly fine sand mixed with mud. The difference between high and low water at the mouth of the river is 10½ feet, but in the harbour itself it is only 7½ feet, owing to an inflow of sluice water and a defective outflow. At low tide and with the depth fixed upon for the dredging channel, the dredger would be aground, and the average working time be thereby reduced to seven hours. It was necessary that the dredger should dredge its way into shallow water, to keep to the proposed line of channel, which passes through clay and sand banks, as well as land projections. As the dredging into high banks was required, a very strong bucket-frame and chain of buckets was constructed, and so arranged that it could work in advance of the bow of the dredger, to the fore part of which a side motion was given, so that, as the silt and gravel were dredged up, a free channel was being made for the dredger itself. The buckets move in a longitudinal opening 5½ feet wide, which divides the fore part of the dredger into two equal parts, there being a strong curved iron girder at the bow. Iron standards erected amidships carry the upper four-sided barrel of the bucket-frame and the hoppers.

The steam engine, which has two cylinders 16 inches in diameter and a stroke of 21 inches, works a common shaft, making 70 revolutions per minute, with a boiler-pressure of 1½ atmosphere. The power is transmitted to a drum for raising and lowering the bucket-frame; to the upper square chain-barrel, also to a steam warp on the port side of the dredger, for hauling the vessel and lighters, and to the apparatus for giving side motion to the fore part of the vessel. This latter consists of two grooved drums geared together by spur wheels, both drums having the same speed and direction of rotation. A strong chain, 0·827 inch thick, makes four turns and a half round the drums, which are reversed by the alternate gearing of two bevel wheels; the dredger being thereby hauled from one side to the other. The side-chains are led, from the drums below, through hawse-holes on to the deck and over guide rollers near the fore girder, where the chains enter the water and are anchored at from 150 to 200 yards from the dredger. The side motion is at the rate of 26 feet per minute.

The bucket-frame is composed of two iron lattice-work girders, strengthened by cross stays. The length of the frame, from the centre of the axle of the upper chain-barrel (four-sided) to the centre of the axle of the lower chain-barrel (five-sided), is 65 feet; and it carries on fourteen rollers an endless chain of sixty-eight links, to which are riveted thirty-four buckets of 5·65 cubic feet capacity each.

The slanting position of the dredger admits of its dredging in water so shallow that it can no longer float. It is important that the head chain starts at a point in the longitudinal axis of the dredger, and that the fore side-chains leave the vessel at a point

as far forward as practicable. By this method the speed of the side motion given to the lower bucket in contact with the bottom remains tolerably constant, although the angle formed by the head chain with the axis of the dredger alters.

In conclusion the Author gives the average work done by the steam dredger. This amounted to 90 cubic yards of soil per working hour, as measured in the lighter. The greatest amount of work was 182 cubic yards of light material that can be easily shot from the buckets. The consumption of good West Hartley steam coal is estimated at 2½ lbs. for each cubic yard of medium heavy sand soil measured in the lighter; this calculation leaves out stoppages of engine and time for getting up steam. The consumption of coal per hour of real working time was 263 lbs. The maximum F. HP. absorbed was 53·1, when dredging in firm sand mixed with clay, and with full buckets delivered at the rate of thirteen per minute; the minimum F. HP. used was 30·2, with light alluvial soil, and full buckets delivered at the same rate, viz., thirteen per minute. The HP. was calculated from indicator diagrams. J. J. W.

The Drainage of Lake Fucino.

By A. Brisse and L. de Rotrou.

(Le Dessèchement du Lac Fucino, Rome, 4to., 1876, pp. 1–304, and atlas.)

Fucino was the largest lake in Central or Southern Italy, situated in the province of Aquila. It covered the greater part of a vast table-land belonging to the territory of the subprefecture of Avezzano, a small town rising at a little distance from its shores. This table-land is one of the largest to be met with in the central part of the Apennines, and is surrounded on all sides by spurs of the main chain of mountains, thus forming a vast basin entirely separated from the adjacent valleys, so that the rain waters falling within its limits possessed no outlet by which to discharge themselves into the neighbouring rivers. The area of this basin is 173,000 acres, and the surface waters of the lake on the 10th of June, 1861, stood at 2,094 feet above sea-level. In consequence of the peculiar conformation of this basin, having no communication with any of the adjacent valleys, and the waters collecting in it having no subterranean or other outlet—no means of escape, in fact, but by evaporation or absorption—it frequently happened that, owing to excess or deficiencies of rainfall, the level of the lake either rose or fell beyond its normal levels; in the former case inundating the valleys on its borders, and in the latter producing unhealthiness from its exposed banks. Julius Cæsar

was the first to conceive the idea of draining the lake; it was attempted by Claudius, and the works which he caused to be executed were considered by Pliny as the most extraordinary of that age. The attempt of Claudius was renewed by Trajan and by Hadrian, and in the middle ages by Frederic II., perhaps also by Alphonso I. of Aragon, and by several sovereigns of Naples, but always in vain.

The area of the lake naturally fluctuated from time to time, but its average dimensions were about 37,050 acres. In form it was very nearly elliptical, its greater axis, running from north-east to south-east, was about 12·4 miles long, the shorter one nearly 7 miles. Its bottom sloped very gently downwards from west to east, and at about 7·4 miles from the head of the tunnel constructed by the Romans to drain the lake, the bottom was very nearly level, and constituted the lowest part of the basin. Beyond this level part, the bed rose again towards the east, but with a much steeper gradient. Owing to the amount of earth annually washed into the lake, it was calculated that its bed had risen 15·65 feet since the time of the Emperor Claudius, when its depth is assumed to have been about 53·723 feet.

The most important, as well as the nearest, of the valleys situated on the other side of the mountains which gird the Fucino basin, is that of the Liris, which, to the west, runs parallel for a certain distance with the plateau of the lake, but at a lower level. The river is about 3¾ miles in a straight line from the lake, but between the two there is a mountain, Mount Salviano, and another plain, called the "Campi Palentini," higher than the lake. As the position of the latter precluded the possibility of making an open cutting between it and the river Liris, the Emperor Claudius determined to excavate a tunnel through Mount Salviano, at about 984 feet below its summit, and under the Palentine fields at an average depth below the surface of 328 feet, in order to discharge the waters from the Fucino into the river Liris at a sufficient height above the latter to enable it, even when in flood, to receive the water from the mouth of the tunnel. This tunnel had its outfall at a level of 41·487 feet above the Liris, and was constructed on a gradient of about 1½ in 1,000. As far as could be judged by the ruins of the tunnel, which it was found necessary to demolish in order to replace it by the tunnel of Prince Torlonia, it had a cross section of 11·9 square yards, and its head is supposed to have been somewhere about 3¾ feet above the then bottom of the lake. In the construction of this tunnel the Romans sank about forty shafts, twenty-nine between the foot of Mount Salviano and the river Liris, and the remainder between the mountain and the lake, ranging from 57·72 feet to over 400 feet in depth. One of these shafts, which was opened whilst constructing the Torlonia tunnel, was found to be square, each side measuring 14·16 feet, and supported in the middle by strong cross beams dividing the shaft into four equal compartments. The tunnel of Claudius was

6,178·59 yards in length, and it passed through the following soils in its course from its outfall to its head:—

	Yards.
Compact limestone rock	708·26
Detached blocks accumulated on the slope of the compact rock	251·30
Pudding stone, composed of rolled gravel embedded in calcareous cement	944·35
Detached blocks	85·25
Compact limestone	826·30
Detached blocks	118·04
Clay and sand	751·98
Detached blocks	118·04
Compact limestone	891·88
Broken rocks in the centre of the mountain	426·27
Compact limestone	453·59
Softer limestone	555·24
Clay	48·09
Total	6,178·59

It will be sufficient here to state that although water is said to have flowed through this channel, its inefficiency soon proved itself, and an accident closed up the tunnel altogether for all practical purposes.

In 1854, however, Prince Alexander Torlonia decided to carry out the drainage of the lake at his own expense, and he entrusted its execution to M. de Montricher, who was assisted by M. Henri Bermont and M. Alexander Brisse.

In determining the section to be given to the Torlonia tunnel, the conditions of possible rainfall and the capacity of the Liris to receive the discharge were considered. On the former point much uncertainty existed, but M. de Montricher came to the conclusion that under no circumstance should a volume of water greater than 11,000 gallons per second be discharged into the Liris, and this quantity was also found to agree with that of the supply of the lake during a hypothetical rising of 5 feet 10 inches in two months. M. de Montricher, therefore, resolved upon a tunnel having a cross section of 216 square feet and a general slope of 1 in 1,000, and following generally the Roman tunnel which might thus be utilised as a headway.

The new tunnel is egg-shaped in section, truncated at its small base, and resting on an invert 9·3 feet in span, with a versed sine of 9·6 inches. The greater axis measures 19 feet from the bottom of the invert to the crown of the arch; the lesser one, 13·1 feet at a height of 12½ feet above the bottom of the invert, which gives a profile having an area of 211 square feet. The slope is generally 1 in 1,000, and with a depth of water of 17·25 feet upon the invert, the discharge is 11,000 gallons per second. The datum point was fixed at the outfall of the tunnel, 33 feet above the bed of the river, and 8½ feet below the Roman invert at that place. The deepest part of the lake was at this time 48 feet above datum, and at a distance of 11 miles from the bench-mark at the outfall. The surface of

the lake was 98 feet above datum, and its depth 50 feet. The invert of the Torlonia tunnel, at its outfall on the Liris, was placed 6 feet above datum, or 2·65 feet lower than the Roman tunnel at that spot. Thence it is carried at a slope of 2 in 1,000 for the first 393 yards, and at 1 in 1,000 for the rest of its length.

The works were commenced by the construction of a dam, to cut off the waters of the lake from the head of the Roman tunnel. This dam was formed by two parallel arms, 240 yards distant from each other, and connected by a curve of 120 yards radius, its total length being 1,640 yards. Its top was protected by a strong stone revetment, and for further protection an inner dam was also constructed, with a space between the two of about 32 acres. About 196,200 cubic yards of earth and 39,300 cubic yards of stone were employed in the construction of these works. The tunnel was commenced at the outfall towards the end of 1855, the greater part of it being constructed with hewn stone, brickwork only being occasionally introduced. Considerable difficulties were experienced during the progress of the work, owing to the quantity of water met with in the shafts, the workmen having sometimes to labour in water and mud up to their waists. As soon as the first 5,084 yards of tunnel had been completed, a communication was opened with the old Roman tunnel, into which the waters of the lake were directed, in order to reduce their head before completing the works. This preliminary draining lasted four hundred and seventeen days, and reduced the level of the lake by 14 feet, after which the tunnel was continued as far as the head of the Roman work, when a second draining of the lake was commenced, a canal being cut to direct the waters of the lake to the tunnel. The surface of the lake, at the completion of this draining, was lowered another 25 feet, its depth reduced to 18½ feet, and its area to 23,230 acres. The tunnel was completed in November 1869 to a length of 6,887 yards, of which 2,813 yards were excavated through the compact rock without revetment, 344 yards through pudding stone and lined with brick, and 3,729 yards through clay, detached rocks, &c., and lined with strong masonry of hewn stone. For its construction twenty-eight shafts were sunk or repaired, having an aggregate length of 1,560 yards, and two inclined galleries, together 568 yards long. The deepest of the shafts made use of for removing the excavated material was 154 feet, and the shallowest 55·44 feet. Twelve of the twenty-eight shafts were above 279 feet in depth.

For the last 22 yards of its length the tunnel gradually widens, and at its mouth is divided by a cutwater into two small tunnels, each of which is fitted with a sluice gate; and 7 feet advance of this is the real entrance, consisting of a semicircular in arch springing from vertical side walls 197 feet apart, and in front of this again is a regulating basin. In order to drain the lower part of the lake, a canal was excavated leading to the head of the tunnel, having the same capacity as the tunnel itself, and a slope of 1 in 6,959, its bottom width being 49·21 feet, and its

sides having a batter of 45°. This canal, 8¼ miles in length, was formed by dredging, effected whilst the waters were still being drained off from the lake. The further works undertaken to complete the reclamation of land consisted of 130 miles of roads, 62 miles of canals and drains (inclusive of the main canal, but exclusive of the tunnel), and 402¼ miles of ditches, and the land reclaimed amounts to 35,012 acres.

The total aggregate cost of this work to Prince Torlonia was 43,137,208 francs, or about £1,800,000. Of this a little over £1,000,000 sterling was the cost of the tunnel, canal, and drainage works generally; £600,000 for compensations, roads, bridges, drains, and incidental expenses, including 5 per cent. interest on capital during construction of the works, and something under £200,000 for preliminary expenses, purchase of concession, contribution towards improving the channel of the river Liris, and other minor incidental charges.

It is calculated that, by the increase in value of land previously cultivated, the drainage of Lake Fucino has added £160,000 to the wealth of the proprietors along its shores, which it is expected, in the course of a few years, will still further increase. In addition to this there remains the 35,012 acres reclaimed from the lake, the proprietary of which is vested in Prince Torlonia in return for his expenditure in the construction of the works.

F. C. D.

The Port of Havre.[1] By Q. DE ROCHEMONT, Assoc. Inst. C.E.

(Report made to the Congress of the French Association for the Advancement of Science, Havre, 1877.)

The port of Havre, the second in importance among the ports of France, is distinguished by special features. Situated on the shores of the Atlantic, it is subject to high tides, which are attended by a remarkable phenomenon that is displayed along the entire level from Cherbourg to Dieppe. This is the *étale*, or slack water; in virtue of which the high tide remains stationary, not for the usual brief period, but sometimes even for hours. An extraordinary advantage is thus secured to Havre over other French ports opening on the ocean; as the period during which vessels can enter or leave the basins is thus prolonged.

Havre is commonly called the Port of Paris, from which city it is distant 141 miles. The two cities are connected both by railway and by the navigable river Seine. The utility of the latter as a means of communication, however, is much impaired by the sand-banks and other difficulties of the navigation. Not only large ships,

[1] The first portion of this Paper is taken from an article in the Giornale del Genio civile, vol. xv., p. 250, "On the Harbours of Havre and Marseilles," by G. Balzaretti.

but middle sized and even small vessels are unable to ascend the Seine during neaps. The project of improving the channel of the river, so as to secure a minimum depth of 10 feet 6 inches, is under discussion. But the chief intercourse at the present time is carried on by railway.

The entrance of the port has hitherto been not without risk, especially by night. The width between the two long jetties, which form the north and south walls of the entrance, is 248 feet. If vessels approach from the north, they need to tack suddenly to enter the port; and the failure of the manœuvre almost inevitably entails their being driven on to the great sandbank at the mouth of the Seine. The entrance channel moreover is curved, so that the larger vessels arriving at Havre are necessarily tugged into port, unless they can make use of their sails. The large ships of the General Transatlantic Company, and the mails, are at times unable to enter the port.

The present communication between the railway and the port is twofold. (1) Two lines of railway track lead from the goods station of the railway along the north quay of the great basin known by the name of Vauban. (2) Two other tracks, starting from the same station, are conducted into the great yards situated between the *entrepôt* dock and the general warehouses. These branches have the common defect of starting from the same point of the main line, almost at right angles, so that but for a sharp curve they would be unavailable for engines. In addition to this they have no sidings, a defect which becomes very inconvenient alongside of the Vauban basin. The length of the track here is 740 yards, in which distance there are only two loading platforms, and one crossing from the up to the down line; an arrangement far from sufficient for the loading and unloading of vessels.

M. de Rochemont, in his Paper, gives details of the works recently executed, and still in progress, for the improvement of this port. The completion of these works will allow a vessel entering the harbour to describe an arc of a circle of 1,000 yards radius, instead of being restricted, as at present, to one of a radius of less than half that length. Accommodation will also be given in the new fore port to tugs and relays, of which the number sometimes is as high as eighty.

The curved quay and the south jetty will be demolished. The Florida basin will be divided into two parts by a traverse or cross wall; the smaller or eastward portion will be turned into a half-tide basin; the remainder will be joined to the fore port. An entrance 88 yards wide will give access to the new fore port, which will be separated from the old one by a mole in masonry. The south jetty, rebuilt in the rear of its present site, will join the quay wall of the old Florida basin. In the space between the outer wall, the new south jetty, and the fortifications which protect the entrance of the port, will be constructed a large breakwater, and a ramp to descend on to the south wharf.

The width of the old fore port, in the middle, will be increased

from 98 to 201 yards. The additional port will cover an area of 316 yards by 109 yards. The mole will be 376 yards long, with a width varying from 28 to 68·6 yards; it will be terminated by a masonry tower. The breakwater will be 114 yards long.

The area of the fore port will be increased from 27· to 52·77 acres. The length of quays available for ships will be 1,951 yards, and the surface of the platforms will contain 36,414 square yards. The height of the quay walls will be never less than 39·36 feet, and will sometimes exceed 45·28 feet; their foundations will be 10·16 feet below datum. The sill of the breakwater will be 7·05 feet above datum. The chamber will have a mean width of 56·4 yards. The stockade will be of metal. A paved road will be constructed round the breakwater, and will allow vehicles to arrive at the end of the jetty.

The bulk of excavation will be 1,267,560 cubic yards, of which 382,200 will be dredged. That of the demolitions will be 111,775 cubic yards, of which 85,800 will be tide-work. Three thousand nine hundred piles will be driven, the aggregate length of which will amount to 27,402 yards. The cubic contents of the temporary woodwork required will be 118,565 cubic feet. The masonry of all kinds will amount to 110,370 cubic yards, of which 34,150 will be tide-work. The cost will be £296,000. The general excavation has been executed under the protection of sheet piling, the work having been commenced by the formation of the traverse (in earthwork) which divides the Florida basin, and by walling up of the scouring sluices. The completion of the breakwaters, some embankment, the demolition of the curved quay, and that of the sluices will be by tide-work. The lowering of the bottom of the fore port is effected by dredging.

The excavation has been executed under favourable conditions after complete drainage by means of powerful pumping apparatus. The soil consisted, above, of sand and gravel from the shore; below, of more or less argillaceous mud, traversed by beds of peat. These strata, very variable in thickness, rest on the bed of gravel which underlies the whole of Havre. Over the site of the works the depth of the bed varies from 7·87 feet to 46·24 feet below datum. In the southern part, the argillaceous sand disappears at some points, and is replaced by a fine quick sand.

The walls of the mole and the east wall have been founded on piles driven in at the bottom of the excavation. The earth was removed to the depth of 10 feet, under the protection of boarding, and then the piles were driven and the masonry built on them; the boarding being removed as the work was carried up. The cubic contents of this boarding was 900 cubic feet per yard run of wall.

The works on the side of the fortifications and the breakwaters could not be constructed in this manner, owing to the quicksands. It was necessary to sink shafts in masonry.

Two lines of piles were driven, on either side of the site of the wall, and 4·9 feet apart in each row. Longitudinals were nailed

to the piles, and kept up the earth. The excavation was carried down nearly to the top of the quicksand. Wooden frames, of different dimensions, but of the same area on plan, were placed on the bottom of the cutting. These frames were formed of three rows of joists, placed one on another. They were 10 inches thick, and bevelled; their width was 1 foot in the lower part, and 2 feet in the upper. On each frame was built a crown of brickwork, each course being set to jut 2 inches over the course below, till the shaft-work had reached its normal thickness. When the mortar had properly set, the workmen mined under the frame, and the material excavated was removed from the trench. The brick shaft sank in consequence. As soon as its top reached the bottom of the excavation a fresh crown of brickwork was built up. This operation was continued until the bed of quicksand had been passed through, and the depth of 9·34 feet below datum was reached. The shaft was then filled up with concrete. The space between these shafts was afterwards concreted, the sides being protected by wooden panels during the excavation. In some places the sand was so quick that it was necessary to caulk the joints of the wooden panels.

The frames measured, in general, 19·68 feet square. They varied, however, from 19·68 by 26·24 feet to 12·13 by 18·69 feet. The thickness of the brickwork varied from 32 to 45·6 inches, averaging 41·2 inches.

The site of the fortifications presented special difficulties, which were overcome by a combination of the two above-described modes of procedure. In order to carry on the work over the site of the former sluice, shafts were constructed, of which three sides were of brickwork, as before, and the fourth of planks. This plan succeeded without misfortune.

The material removed from the shafts exceeded by 24 or 25 per cent. the cubic contents of the masonry and concrete employed to fill them. This difference represents the increase of the material in bulk, and the additional material that ran in from the sides.

Down to the 8th of October, 1876, when water was let in, the pumping was carried on by three sets of apparatus, each consisting of two movable steam engines and two pumps. The construction of part of the works of the mole required an engine and pump in addition. Another engine and pump was supplied for the frames. The engines, of the nominal power of 18 HP., really did the work of 30 HP. Four engines, at least, were constantly at work, the others being added at high tides or in stormy weather. Every care was taken to reduce the height of the lift, which varied from 16·4 to 43 feet, but usually was from 25 to 33 feet.

The number of hours for which the engines were under steam was 94,948. Of this time the pumps were worked for 89,718 hours. Allowing 4 metric tons per minute for each pump (which is below the truth), the total volume of water raised must thus have exceeded 21,000,000 metric tons.

The works remaining to be executed will be performed by tide-

work, and the demolition of the old walls will be effected under protection of sheet piling. In addition to these works of marine construction, sheds will be built and rails laid on the quays. The width of the entrance of the port will be enlarged from 82 to 109 yards. A new graving dock will be built, able to receive a vessel 460 feet long; and a canal of 15½ miles in length, to float boats drawing 10 feet of water, is in contemplation from Havre to Tancarville, at that distance up the Seine. The estimate for this canal is £840,000.

F. R. C.

The Horta Harbour of Fayal, Azores.

By A. K. DE B. AYALLA.

(Revista de Obras Publicas e Minas, Lisboa, vol. viii., pp. 329–348.)

The Author points out that the position of the Azores Islands, in mid-ocean between Europe, America, and Africa, and near the course of the Gulf Stream, is one of considerable importance to vessels requiring to put into port for repairs or for other purposes, and gives an account of the plans which have been proposed from time to time to improve the harbour of Horta, at Fayal, one of the westerly islands of the Azores group. The Bay of Horta is admirably designed by nature for the purpose of becoming an important port of call. It is semicircular in shape, with a mouth about 2 miles wide, and has a sandy bottom which affords excellent anchorage, with sufficient depth of water to allow vessels to approach within 200 yards of the shore. It faces the south-east, and is sheltered from the north by Cape Espalamaca, which rises 420 feet above the sea; from the south by Cape Guia, 485 feet high, and from the west by Mount Carneiro, having an altitude of 885 feet. On the east and south-east points are situated the islands of Pico and S. Jorge, at a distance of 5 and 25 nautical miles respectively, and their mountainous character affords protection to the bay from the direction whence the most dangerous storms are experienced in these latitudes.

The Author proceeds to give statistics showing the amount of tonnage entering the port, together with the Custom House returns, and argues thereupon that the improvements now being carried out will be of great value to the further development of the commercial importance of the place.

At various times offers were made by companies for the construction of an artificial harbour, on the basis of being allowed to charge certain dues and to receive a percentage on the custom house and other revenues of the island, but none appear to have been acceptable, and finally the Government determined to carry out the work themselves.

The plan decided upon consists of a breakwater 2,165 feet in

length; the first portion, having a length of 984 feet, is being constructed upon a reef of rocks mostly from 10 to 13 feet under low-water mark. The remainder will be made in depths commencing at 13 feet, and rapidly increasing to 70 feet at the end of the breakwater. The shape on plan is polygonal, consisting of three pieces of straight connected by short curves, and so placed as to shelter an area of about 27 acres; this, it is estimated, will afford anchorage to more than one hundred vessels at a time. The cross section of the breakwater is an adaptation of those at Marseilles and Holyhead combined, as follows:—The hearting will be formed each of random stones, weighing less than 2 tons each, and carried up to 16½ feet below low-water mark, with a top width of 36 feet, and slopes of 5 to 4. On this, and also on the outer face, will be placed blocks of natural rock, exceeding 2 tons each in weight, to make up the bank to 5 feet above high-water mark. The average range of the tides is about 5 feet. Finally, the exterior slope will be protected by artificial stone or béton, in blocks measuring 11·2 feet by 6·6 feet by 4·9 feet, and containing each 13⅓ cubic yards. At 25½ feet below low-water mark the slope will be set back 20 feet to take the blocks, which are thrown upon it to a height of 5 feet above high water. The lower portion remains unprotected, as it is considered that the action of the sea will have no injurious effect at that depth.

On the outer side of the embankment a sea wall will be built, of large rubble work without dressing, the foundations to be placed at low-water level, and the footings protected by the blocks of béton for a depth of 10 feet. It will be 30·2 feet high, and 16·4 feet wide at the top, the side facing the harbour being vertical, and the outer side made with two batters, the upper 25 feet at 1 in 25, and the lower portion at 1 in 4. The summit will be surmounted by a bold curved cornice and a parapet 4 feet high and 4 feet wide, leaving 12·4 feet of wall available as a promenade.

The harbour side of the breakwater will have a quay for the use of shipping. At 19·7 feet below low-water mark the slope will be recessed 15 feet, and thereon will be built a béton wall of blocks in courses 11·5 feet wide and 3·3 feet thick, breaking joint and having a batter of 1 in 20. A set back of 1 foot is then left, and a rubble wall carried up to 5 feet above high-water mark, which will be 6·6 feet thick, ashlar-faced and finished with a coping. The available quay space will be 48·2 feet wide, and extending for the whole length of the breakwater.

The works were commenced on the 25th of March, 1876, and during that year tramways were laid down, quarries were opened, and various buildings, plant, and machinery were erected for the purpose of carrying out the work with proper regularity. The total estimated cost is £266,700.

G. Kn.

Works for the Protection of the Sea-coast at Cranz.

By H. HERZBRUCH.

(Deutsche Bauzeitung, vol. x., pp. 398–399.)

Cranz is a village on the Baltic which has become a favourite sea-bathing resort. It lies 16 to 20 feet above the level of the sea, near a cliff of loamy clay, which the sea has been gradually washing away for years. Some twenty years ago a few short groynes were erected, and private landowners and the Administration of the Baths constructed some stone pitching on fascines, and protected by a few short piles. But these works were insufficient, the groynes not having been carried far enough back into the cliff. In the winter of 1873–74, in consequence of heavy storms, the rear of some of the groynes was washed out, and a strong current ran behind them, which broke away a great deal of the cliff. At the same time, the fascines having gradually decayed, the pitching sank, and the Corso, or seaside drive, was in danger. A sum having been voted for sea works, the following were carried out:—

1. The existing groynes were largely strengthened and carried back well into the cliff, and new ones were added. The piles forming them are 13 inches apart, the heads being cut off at mean water-level. The groynes are carried out to a depth of water of 5 to 6 feet.

2. To protect a length of 575 feet of the Corso which is nearest the cliff, a substantial retaining wall of rubble masonry, 10 feet thick at the base and 4 feet 10 inches at the top, was erected, provided with a footing, also of rubble, which was carried down 3 feet below the mean water-level, and protected against wash by a close row of small piles, 3 feet 6 inches long, and by the foot of the old pitching. The top is dressed off with a gentle slope, which is turfed as far as the road. This wall cost £4 per lineal foot.

3. As it would have cost too much to protect the whole foreshore in the same manner, the remainder was provided with a longitudinal breakwater, filled with fascines. This consists of a double row of piles, 3 feet 3 inches apart from centre to centre, the front row battering at about 1 in 4 towards the shore, the rear row being vertical. The latter is driven about 10 feet from the face of the cliff, and connected with it by a row of piles driven at an angle of 45°, the heads being secured to those of the rear row. Each row is cut off 6 feet 6½ inches above the mean water-level, and has a longitudinal brace bolted to the heads, with a cross brace under it tying the two rows together. Substantial fascines were placed at the bottom between these rows of piles, the rest of the space being filled up with loose branches. Two other free longitudinal rows of piles are driven in front of the breakwater, 6 feet 6½ inches and 13 feet 1 inch respectively from it, each supplied with a longitudinal brace, a substantial plank driven horizontally into the

sand at the foot, and a small stockade, the two latter intended to prevent the back wash. The piles are all 8 inches by 8 inches, from 10 to 12 feet long. The cost was £1 10*s.* per lineal foot.

The effect of these works has been excellent, as the groynes are mostly covered with sand to their tops, and a foreshore has been formed between the breakwater and the front row of piles. In the Author's opinion, groynes formed of single rows of piles some little distance apart answer better than double ones formed of close rows. E. D'A.

New Quays and Docks at the Port of Amsterdam.

(De Opmerker, Sept. 16, 1877.)

The North Holland Canal having been opened on the 1st of November, 1876, arrangements are being made for large new docks and quays. The extensive cattle traffic with England necessitated a new jetty and stabling accommodation; and as, by terms of the contract, the canal must be deep enough for ships drawing 23 feet on the 1st of November, 1877, it was incumbent upon the authorities to increase the size of the locks, which had only 19 feet 4 inches of water above the sills, when the level of the canal is 11·8 inches above A.P. A quay 1,300 yards long, 180 feet broad, and 5 feet above A.P. is in course of construction from the goods station of the State railway, parallel with the East Quay, and ending at the entrance of the Eastern Dock, leaving an opening of 280 feet, and forming with the East Quay a harbour for coasting vessels. The depth outside the outer wall will be 23 feet 8 inches, that on the inside 10 feet 6 inches.

The usual method of dredging a channel in the mud to the required depth, and filling up with sand, was not followed. The depth of the Y at the greater part of the proposed quay was only 4 feet below ordinary level, but at the west end, near the dock gates, the depth is 39 feet, and it was resolved to form a wall by discharging sand from barges, and allowing it to displace the mud by its own weight. This was commenced on the west side in 1875, and continued through 1876; but the displacement was so considerable that, although 230,000 cubic yards of sand were discharged, no permanent ground was established above water-level. In 1876 the railway company commenced discharging on the east side; large quantities of mud were soon displaced, and firm ground formed, which could bear a double line of rails. Two parallel embankments of sand were then discharged in the direction of the outer and inner walls, and when it was found by boring that a depth of 24·6 to 26 feet below A.P. had been reached, the mud displaced, and that still remaining between the embankments, was utilised for filling, it having been found that its consistency after pressing and drying was sufficient. The outer wall in course of construction consists of a foundation of concrete 10 feet broad,

resting on piles, from 8 to 20 feet below A.P., upon which a basalt wall 7 feet broad will be carried to 5 feet above A.P. Behind this basalt wall there will be one of concrete, also resting on piles 33 feet broad, and carried down to 8½ feet below A.P., which is expected to give sufficient stability to the sand filling.

There is also in course of construction a timber-harbour, provided with spacious jetties, quays, and sheds, with an area of 250 acres, intersected by sheet piling so as to break the waves and allow of the making up of rafts. Near the West Docks two jetties have been run out into the Y, each 400 feet long and 200 feet broad, and each resting on 4,750 fir piles 60 to 73 feet long. Other works of a similar character are sanctioned.

J. D. L.

Repairing Slip at the Hernösand Works. By V. M. Ström.

(Ingeniörs-Föreningens Förhandlingar, Stockholm, 1877, pp. 4–5.)

This slip was constructed for drawing up ships "broadside on," and was so designed to provide for the large number of steamers which have to be laid up during the winter months. The level part, which is laid on shore, is about 240 feet long by 83 feet broad. On it nine steamboats of 120 to 140 feet in length can be laid up, or eighteen to twenty of 50 feet, these latter in two ranks. The inclined part, or slip proper, which is under water, is about 115 feet in length, and is laid with a gradient of about 1 in 8·3.

The structure consists essentially of three lines of railway parallel to each other. Each of the side lines is laid with ordinary rails, with a gauge of 12 feet, and the distance between their centre lines is 71 feet. The middle way, on the contrary, has three rails on each side, viz., two flat-headed rails laid about 2 feet apart, and between them a rack; the gauge of this railway measured from centre to centre of the racks is 16 feet. Each rail is carried on a balk of timber 12 inches by 10 inches, laid longitudinally, and spiked to transverse sleepers, which, in their turn, are bedded on another set of longitudinal timbers. The three lines are held together by ties running through from side to side at intervals of about 12 feet, and the whole is stiffened with diagonal bracing. That part which is under water is covered with a flooring of planks, partly to prevent it settling into the bank on which it rests, and partly to carry the ballast for sinking it. The sea bottom is gravel and stone, covered by a stratum of mud, which increases from 5 feet near the shore to double the thickness at the outer end of the slip, where the water is 12 feet deep. The bank was made of earth and gravel, with a top layer of stone and sand close to the shore to prevent damage from the waves; during its construction the site was inclosed by a temporary breakwater.

The carriage, upon which the steamers are drawn up, is of

timber, stiffened with cast-iron knees where the longitudinal and transverse pieces cross each other. It is about 16 feet long and 83 feet wide, and is carried on forty wheels or rollers, which run four on each rail, viz., one leading, two middle close together, and one trailing; those which run over the racks are grooved, so that they may clear the teeth while their flanges bear on the flat plates on which the racks are bedded. The axles are of Bessemer steel, and are calculated to bear a load of 500 tons with safety. Hinged to the edges of the carriage are twelve arms, six on each side, which can be moved into various positions in their planes of rotation by blocks and tackle connecting their upper ends to chains led from points in the centre line of the carriage. These hold the steamer like so many pairs of tongs, and serve to guide it into the proper position over the carriage before it is hauled up. There are also six fixed arms on each side, projecting nearly horizontally outwards, which support the lower ends of the props by which the vessel is steadied. To insure the carriage moving square with the rails, the two end timbers are made to project about 6 feet. To the front end of each of these is pinned a casting, which can only move in a vertical plane, carrying an upright post which bears an index board. On a pin projecting from the front end of each casting is fixed a pointer, movable only in a plane perpendicular to that in which the casting itself can move. The lower end of the pointer carries a wheel, or grooved pulley, which runs along the outer rail of the slip. Thus, unless both ends off the carriage advance equally, the projecting pieces and castings above mentioned do not remain parallel with the rails, and vertically over them, and the pointers are deflected from the vertical, and from coincidence with the centre lines of the index boards which are behind them. The lengths of the parts are so arranged that when one end of the carriage is 6 inches behind the other, the tops of the pointers are moved 1 foot from the centre lines of the index boards.

The hauling up is accomplished by three capstans, one at the end of each railway. The middle one works an endless chain, which also passes round a pulley at the lower end of the slip, and renders both a forward and backward motion possible. To hold the carriage on the incline, pawls are fitted to the under-side, which fall into the racks. When a vessel is to be laid up for the winter, the carriage is sunk to the required depth, the ship is drawn over it, and guided into position by the arms and tackle already described; when it has arrived on the level part of the slip, greased slides and cradles are arranged under the keel. Upon these the vessel is steadied by props. It is then dragged off the carriage by the capstans and shored up in the usual manner, lying of course athwart the slip. By means of a lighter carriage running on one of the sideways only, a small vessel may be drawn out of the water and shored up on the slip in a single day. When the large carriage is used, about a day is required for the hauling up, and two or three more for finishing the work.

M. L.

The Waterworks of Aix-la-Chapelle. By J. STÜBBEN.

(Deutsche Bauzeitung, vol. x., pp. 194–195.)

The water supply of the town of Aix (now numbering about 95,000 inhabitants) was long a matter of great perplexity, owing to the peculiarities of its situation. It lies at a distance from any rivers or large springs, in an undulating country producing a multitude of rivulets, too small to be of much value. Some of these pass through the town and have become little better than drains. Others have been brought into it by pipes, but form a very insufficient source of supply. The matter is further complicated by the presence of the hot sulphur springs which feed the well-known baths of the place. The fear of disturbing these, and also the streams already utilised, precluded any attempt to obtain water close to the town. A scheme for damming the upper waters of the "Hohe Veen," a stream about 9 miles to the south, and bringing a masonry aqueduct from thence to the town, was rejected on the score of expense. Finally it was resolved to seek a supply in some chalk hills which run through the district in long ridges from S.W. to N.E. The plan adopted was to drive a horizontal gallery into the chalk at such a level that the water when found might flow into the town by gravitation; and this has now been successfully carried out. The gallery (which is about 3 miles from the town) is about 6 feet 3 inches wide by 7 feet 3 inches high, and driven with a rise of 1 in 20. Ventilating shafts are provided at distances 820 feet apart, the whole length of the gallery being at present 3,770 feet. The supply of water obtained varies from 1,850 to 2,900 cubic yards per twenty-four hours. As this is not a sufficient supply, the gallery is to be driven a considerable distance farther. Pending its completion a well is being sunk close to the line of the gallery into the trough formed by a bed of slaty rock which runs through the chalk strata; and a 120-HP. engine is being erected to pump water from this into the aqueduct, so as to increase the immediate supply to the town.

The water thus obtained from the chalk is of course somewhat hard, but is excellent for drinking, analysis giving only 2 parts in 100,000 of lime, of which only one-tenth is in the objectionable form of sulphate, the rest being carbonate.

The pipes and other distributing arrangements are being made on the scale proportionate to the full supply. The water is first led in a channel of cement to a filter and service reservoir, and from thence to an open space just outside the town. From thence one line of mains runs in a complete circle round the outskirts of the town, and another is led diametrically through it to the opposite side, where it unites again with the first. Another reservoir is erected at this point, to equalise the pressure and give a special supply in case of fire, &c.

The estimated cost of the whole works is £112,500.

W. R. B.

Second Report on the Water Supply, Sewerage, and Removal of Refuse of Munich, 1876–77.

(Berichte über die Verhandlungen und Arbeiten der vom Stadtmagistrate München niedergesetzten Commission für Wasserversorgung, &c., München, 1877, pp. 1–212, 15 pl.)

This Report is issued under the authority of a committee composed of the magistrates of Munich, associated with a number of scientific men, and records their proceedings from the commencement of the year 1876 up to May 1877.

Munich at present draws its water supply from town wells, thirteen in number, yielding an average of 6,792,394 gallons every twenty-four hours; and the population being 193,456 (it has increased to the extent of 23,776 in a period of four years), the supply per head is equal to 35 gallons, which quantity, however, after a dry summer, or during a hard winter, is occasionally reduced to 20 gallons. According to Dr. Wolffhügel, of the Munich Polytechnic, the city possesses fifteen wells, which yield 85 gallons per second, or about 7,340,740 gallons per twenty-four hours; sufficient for a population of 200,000. This, however, is the mean quantity, which is occasionally reduced to two-thirds, or even one-half. Of all these the Thalkirchen well is the only one sufficiently pure to be used for drinking water, and this contributes one-seventh of the total quantity. Detailed analyses are given of the water of these wells by Dr. F. Renk, for the twelve months ending November 1876, which show the amount of organic and inorganic impurities to be so considerable, excepting in the case of the Thalkirchen water, as to render it quite unfit for drinking purposes.

The earlier portion of the Report refers to the sources from which a supply of water sufficient in quantity and purity for the town service may be best obtained. The results are tabulated of a series of observations made by Herr Salbach, with regard to utilising the springs of the Mangfall Valley. These observations, which were made fortnightly, and extended from August 1876 to May 1877, show the water-flow and temperature of five different springs during that period, the greatest yield being in the month of February, when it amounted to a total of about 22,000 gallons per minute. The analyses of these waters, by Dr. Wolffhügel and Professor Buchner, is given with a report upon the Kesselberg springs; and a table showing the total water-flow of thirteen springs in that district, varying from 6,000 gallons to 110 gallons per minute. Analyses of these waters, by Professor Wagner, proved that they were, with the exception of one which was impregnated with carbonate of soda, all suitable for drinking water.

The proposition to obtain a supply from the river Isar above the town is regarded as not feasible, on account of the quantity of matter in suspension at certain seasons, also with reference to the

high temperature in summer, and again, in winter, the difficulty there would be in preventing the freezing of the filter beds and reservoirs.

As regards the disposal of sewage, in communications received from the General Committee of Agriculture of Bavaria and other agricultural societies, concerning the comparative advantages of a water-carriage system and the removal of sewage and refuse by land carriage, a decided opinion is expressed against the former method, on the grounds that the climate is unfavourable, and that valuable manure would thereby be wasted. The adoption of either the Liernur or the pail systems is recommended. The Public Works Department also urge the adoption of the latter method, and offer to provide, if necessary, trucks for the removal of the sewage and refuse to a depôt situated at some distance from the town.

The Report of the Institution of Bavarian Architects and Engineers is to the effect that the water-supply question depends so much upon the system of sewerage to be adopted that the latter must be first determined. It refers likewise to the system of sewerage proposed by Mr. J. Gordon, M. Inst. C.E., which is objected to on account of the outlay, the large quantity of water required for flushing purposes, and the probability of the pollution of the river below the sewer outfalls. The Report recommends the adoption of the more economical mode of providing movable tubs for each house, or in confined situations where it would be difficult to shift these, that there should be fixed iron receivers, which could be emptied pneumatically, and the contents removed in transport casks to wherever it might be required as manure.

Notwithstanding this Report it was resolved, by the Committee of Magistrates, to inquire further into the sewerage project proposed by Mr. Gordon, and to call in the assistance of two experts for the consideration of his estimate. This is given in detail in Supplement No. 2, for a complete system of sewerage for the whole town, the dimensions of sewers and side-drains, with their lengths and prices per lineal mètre, for each street, being stated, so as to simplify amendment in case any modification should be considered desirable. The sewers are proposed to be constructed at an average depth of 16·4 feet below the surface. The project is divided into an upper and lower system on each side of the river. The total estimate amounts to £627,269 8*s*.

Dr. Gümbel describes the geological formation of Munich and its neighbourhood, as affecting the subsoil water currents (Supplement No. 3). The stratum, which forms what may be termed the water-holding basin, consists of an impermeable bed of marl, overlaid or mixed with flints, succeeded by a layer of sand and pebbles, all of which belong to the tertiary series; the next and also the surface stratum being of pebbles belonging to the present or new series. The depths of these various strata, together with the relative height of subsoil water for January, are given, as well as plans accompanying the Report to show the contour, or horizontal curves of the subsoil water for each month of the year 1876.

At the end of each month the level of the subsoil water was observed at five hundred different points, where borings had been made for the purpose. These bore-holes, at each of which was fixed an iron plate to serve as a bench mark, with the levels written against them in mètres (reduced to a datum identical with the level of the Mediterranean) were shown on Plan No. 1, as were also the subsoil water contours for the month of January. The height of the subsoil water having been observed with reference to these bench marks, the contour, or lines of horizontal curvature, were developed accordingly, as shown by the series of Plans, of which there is a separate one for each month's observations. In addition to these, Plan No. 13 shows by coloured lines a comparison between the highest level (April 29th), the medium level (July 30th), and the lowest level (December 29th) of these subsoil waters; and also defines the position of six cross sections, taken at right angles to and on both sides of the river. The water contours appear to range from 1,660 feet to 1,712 feet above datum. These cross sections are given on Plan No. 14, and show the surface of ground, the position of impermeable marl stratum before spoken of, also the subsoil water-level at its greatest, medium, and lowest heights, being distinguished by coloured lines.

This information will probably be of much practical service in questions regarding foundations, cellars, sewerage, and sanitary works generally.

The question of water carriage *v.* land carriage was discussed, together with Mr. Gordon's project, at meetings of the Institution of Munich Architects and Engineers, on March 15th, 23rd, and 29th, 1877. A report of the proceedings is contained in Supplement No. 4. The subject of the London Main Drainage and other English and Continental sewerage systems was introduced into the discussion, in which Dr. von Pettenkofer took a prominent part, on the question of sewage in relation to the spread of epidemics.

D. G.

On the Discharge of the Permanent Gases, with reference to the Hypothesis of Saint-Venant and Wantzel.

By J. ILLECK.

(Der Civilingenieur, vol. xxiii., pp. 343–354.)

The mechanical theory of heat, applied to the problem of the discharge of permanent gases through orifices, leads to expressions which agree with experiment for moderate differences of pressure, but for greater differences are erroneous, and for the case of discharge into a vacuum give a result which is absurd. It follows that the formula of discharge obtained by Saint-Venant and Wantzel, and later by Weisbach, is not generally valid, because it assumes

the pressure of outflowing gases in the receiving vessel to be equal to the external pressure, while experiment shows that it is greater than the external pressure. By assuming a greater pressure in the outflowing stream in the receiver, the formula of discharge may be made to agree very closely with experiment.

If, then, the at least approximate accuracy of the hypothesis of Saint-Venant and Wantzel is assumed for the discharge under great difference of pressure, with this modification, it still remains to be explained why in the receiver that pressure exists which corresponds to the maximum of discharge. The difference of the law for great and small differences of pressure leads Fliegner to remark that the minimum pressure in the receiver only apparently depends on the maximum discharge, or accidentally agrees with it; and in this Grashof concurs.

The following observations are intended to point out that the equation of movement of the permanent gases, applied without restriction, leads to another contradiction, which only vanishes, if the proportion of the internal pressure to that in the receiving vessel does not exceed a certain limit. Let $F_0 F F_1$ be three successive sections of the stream of fluid, the part $F_0 F$ belonging to the receiving vessel, and $F F_1$ to the receiver. Let $p_0 p p_1$ be the pressures at these sections, and $w_0 w w_1$ the velocities. Let also $F_0 = \infty$, and consequently $w_0 = 0$.

Then there are two cases to be considered.

Case I.—$F > F_1$. Putting for shortness $\frac{F_1}{F} = y$; $\frac{p}{p_1} = x$; $\frac{p_0}{p_1} = a$; the Author obtains the equation

$$y = x^{\frac{1}{\gamma}} \sqrt{\frac{a^{\frac{\gamma-1}{\gamma}} - x^{\frac{\gamma-1}{\gamma}}}{a^{\frac{\gamma-1}{\gamma}} - 1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For $x = 1$, $y = 1$, and for $x = a$, $y = 0$, this gives quite accurate results. When, however,

$$a > x > 1,$$

it gives for $p > p_1$, $F > F_1$, a result which is absurd. If now the curve $y = f(x)$, it is found to have such a form that the straight line $x = a$ is tangential to the curve at the point $x = a$. $y = 0$. For two values of x, namely $x = 1$ and $x = 4{\cdot}216$, the curve has equal ordinates $y = 1$. Between these two values of x, y is greater than 1 and reaches a maximum value. From the previous considerations, this part of the curve for which $y > 1$, corresponds to the case for which $F > F_1$. To exclude these values, the two points at which $y = 1$ must be made to coincide. This will be the case if y max $= 1$ and then max $a = 1{\cdot}8990$, which is identical with the value which gives a maximum discharge in the formula of Saint-Venant.

If now the value of max a is put in equation (2) there is obtained for the section ratio

$$\frac{F_1}{F} = \sqrt{\frac{(\gamma+1)\left(\frac{p}{p_1}\right)^{\frac{2}{\gamma}} - 2\left(\frac{p}{p_1}\right)^{\frac{\gamma+1}{\gamma}}}{\gamma-1}} \quad . \quad . \quad . \quad (7)$$

which is to be applied whenever

$$p_0 > p > p_1.$$

Case II.—$F_1 > F$. In this case it is necessary to have $p < p_1$, and hence $\frac{p_0}{p}$ and not $\frac{p_0}{p_1}$ takes a maximum value.

Proceeding as before,

$$\frac{F}{F_1} = \sqrt{\frac{(\gamma+1)\left(\frac{p_1}{p}\right)^{\frac{2}{\gamma}} - 2\left(\frac{p_1}{p}\right)^{\frac{\gamma+1}{\gamma}}}{\gamma-1}} \quad . \quad . \quad . \quad (8)$$

and this is applicable if,

$$p_0 > p_1 > p.$$

Thus far a solution of the problem of discharge has not been obtained, but only a value for the limiting ratio of the pressure in the discharging and receiving vessel has been found, in a manner more rational than that which connects it with the maximum discharge, with which *à priori* it does not seem to have any relation. The Author then proceeds to give some further considerations tending to establish a theory of discharge. For this purpose he examines what would be the maximum velocity of a fluid stream of given temperature in a pipe of uniform section.

W. C. U.

On Körting's Steam Jet Scrubber. By B. Körting.

(Journal für Gasbeleuchtung, vol. xx., pp. 478–489.)

The object of this scrubber is to remove the ammonia from the gas by the agency of steam from an exhauster, as being the substance which enters into the most intimate contact with the gas. This is accomplished by conveying the warm gas, impregnated with moisture, through a series of vertical pipes in a downward direction, the pipes being filled with coarse shavings. The gas passes through the whole of the pipes simultaneously, so as to diminish the velocity of its flow as much as possible, it being well understood that this is an important element in every condensing process.

The reason why the flow is downwards is, that the gas as it

coals should remain in contact with the products of condensation, which are being cooled at the same time, and which are exactly those intended to absorb the ammonia. With the reverse motion the cooling action would, no doubt, be increased; but the scrubbing effect would be null, since the products of condensation would be heated by the ascending gas, and would part again with their ammonia. The wood shavings serve to attract the vapours mixed with the gas, which vapours when deposited over an extended surface further assist in arresting the ammonia. Both gas and ammoniacal water leave the scrubber at the bottom.

In large works where machinery and superintendence are comparatively small items in the balance sheet, and ammonia is valuable, this steam jet scrubber will not offer great advantages. It is quite different, however, in small and medium-sized works. There the trifling loss of ammonia is of no consequence, whereas the freedom from machinery and skilled labour exerts a most beneficial effect upon the economical production of gas; and for such works, therefore, the present scrubber is to be recommended.

The gas on entering the scrubber ought to be as free from tar as possible; for if through imperfect condensation a large amount of it should still remain in the gas, the rapid motion and simultaneous heating produced by the steam jet would decompose the minute particles of tar, the volatile oils would be retained in the gas in a state of solution, pitch and naphthalin would be formed, and choke up the scrubber in a short time. If the gas is free from tar the wood shavings may remain in the pipes for years without renewal. In Liverpool, for instance, the same shavings have remained for three years in one scrubber; but the system of condensation adopted there separates the tar and precipitates the ammonia thoroughly.

The first point of importance in the scrubber is the equal flow of the gas through all the pipes at once, as also of the water coming from the exhauster, and of what is separated from the gas in the main horizontal pipe. To effect this the vertical pipes are narrowed at the top by a disk carrying a smaller pipe, projecting into the horizontal main by about a quarter of its diameter. The areas of these small pipes together should be equal to that of the main in the works. The second point of importance is, that the liquid particles deposited by the gas in its downward flow should be directed on the middle of the shavings, which is accomplished by inserting a disk with a hole in the middle at the joint of two pipes.

The area required for the scrubbers to absorb the ammonia sufficiently depends upon climate and locality; but, on an average, a production of 1,000 feet per hour requires from 100 to 150 square feet of pipe surface.

The cost of these scrubbers, as compared with those of Man and Walker, is about the same for large works, and for small ones about two-thirds; and their great advantage consists in the absence of all machinery, with the exception of the boiler.

Tests made at Berlin as to the amount of ammonia contained in the gas after it had left the scrubber, and after passing it through a refrigerator in the shape of a scrubber with a finely divided spray of water, showed an average of 23 grammes of ammonia in 3,530 feet of gas. When, instead of this second scrubber, a pipe condenser surrounded by water was substituted, the result was an average of 51 grammes of ammonia in the same quantity of gas. This is a proof that a spray of water is a most valuable contrivance for removing the ammonia. Experiments made at the gas-works at Dessau corroborate the above, it having been found that gas, after passing the first scrubber, lost 5 per cent. of its ammonia, after the second it lost 16 per cent., after the third 33, and after having gone through a fourth scrubber it had lost 84 per cent. The dimensions of the scrubbers with which these experiments were instituted were 8 feet in diameter by 20 feet in height, with plates inserted at intervals covered with twigs.

J. G. H.

On the Manufacture of Gas from Paraffin Oils.

By L. GROTOWSKY.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, vol. xxv., pp. 176–182, 1 pl.)

The raw material employed in the production of illuminating gas from liquid hydrocarbons is the residual oil from the manufacture of paraffin, known in the trade in England and Galicia, according to the character of its fluorescence, as blue or green oil, and in Germany as paraffin oil. This, when allowed to flow over a metal surface heated to dull redness, is decomposed and volatilised, the products being partly condensable, mainly tarry vapours, and partly permanent gases of a very high illuminating power. The proportion of tar to gas is about 1 to 2, or a given weight of oil will produce from 60 to 70 per cent. of gas.

The distillation is effected in retorts, which may either be horizontal and generally similar to those used in making coal, or vertical like those employed in the distillation of lignite oil shales, &c. In the former or horizontal construction, the retort is a cast-iron tube of oblong section, about 5½ feet long, 10 inches broad, and 5 inches high, supported along its entire length by a bench of firebrick, and heated by a grate fire placed below, the sides and top being surrounded by the flame, but not the bottom. The oil is introduced at the hinder end through a tube of the bore of a straw or quill, laid with a slight inclination upwards, that the stream may strike the roof and flow down the sides close to the point of admission. The flow is regulated by a cistern, in which a constant head of oil is maintained. The volatile products are led off by a still-head and goose-neck above the fireplace end to a box containing tar, where a first separation of the tarry vapours

is effected, and subsequently to the condensers proper (which are vertical cylinders filled with fragments of coke), where the rest of the tar is condensed; after which the gas is sufficiently purified for use, and is received in a gasholder of the ordinary construction.

The vertical retort is a cast-iron tube, slightly reduced in diameter at the lower end, set in a furnace with a system of ring flues, so that it may be uniformly heated. The fireplace is below, and at one side of the axis of the retort. A wrought-iron cylinder, similar to that employed in charcoal blast furnaces for the same purpose, serves as a collector for the gas. This is suspended from the top flange of the retort, and is removable, so that it may be taken out and cleaned when necessary. The oil is introduced through a series of small-bore tubes, penetrating the wall of the retort through the top end, and disposed at equal distances around the circumference. The gas collecting and purifying arrangements are generally similar to those in the horizontal form of apparatus.

The vertical construction is considered to be preferable to the horizontal, as giving a larger yield from the same sized plant; an apparatus of the dimensions shown in the accompanying plate with the horizontal retort, producing 600 cubic feet per hour, while that of the vertical form is 750 cubic feet, from oils equivalent to 1,000 cubic feet. In the latter construction it was considered desirable to case the retort with firebrick, either wholly when it is kept in constant use, or partially when it is used intermittently.

The chief care required in working is the maintenance of a proper temperature in the retort, which should be uniformly of a dull red (brick red) heat. If it is irregularly heated, besides the danger of breakage there is a proportionate increase in non-illuminating hydrocarbons and tar, so that the yield is depreciated both in quality and quantity. If uniformly overheated, the decomposition is attended with a separation of carbon, which is deposited as soot in the connecting tubes. When, on the other hand, the heat is too low, there is, in addition to an excessive production of tar, a formation of asphalt, which deposits in the retort itself. The most favourable results are obtained with a yield of 900 or 1,000 cubic feet of gas per cwt. of oil, as, although a more highly illuminating gas may be produced when the yield is smaller, the total illuminating factor per unit of oil consumed will be less; and conversely, with a high quantitative yield, the illuminating value of the gas will be diminished. The firing is regulated chiefly by the colour of the gas as observed through gauge cocks in the still-head, which should be of a clear brown tint. If it is white the temperature is too low, and if colourless with spots of soot, it is too high. The production of tar should be from 26 to 30, or not exceeding 33 per cent., and the tar condensers should keep tolerably cool.

The gas produced is of a much higher density and illuminating power than ordinary coal gas, being very rich in elayl and similar

light-giving hydrocarbons. The following are the comparative figures of various kinds of gas used for lighting :—

	Coal Gas.	Wood Gas.	Peat Gas.	Paraffin Oil Gas.
Specific gravity (air = 1)	0·42	0·75	0·63	0·86 to 0·89
Ethyl and homologous hydrocarbons (C_2H_4)	6·46	10·60	9·52	27·80
Marsh gas (C_2H_4) .	34·90	35·30	42·65	35·60
Hydrogen	45·48	31·70	27·50	33·90
Carbonic oxide, carbonic acid, oxygen, nitrogen, and sulphuretted hydrogen	13·06	22·40	20·33	2·70

The illuminating power of the flame from a standard burner of 1 cubic foot consumption of oil gas per hour is equal to that of thirteen standard candles of 100 grammes; the corresponding value for coal gas being 2·44, or the illuminating power of the former is 5·33 times that of the latter; or for equal cost of lighting, oil gas at 21*s.* 8*d.* per 1,000 feet would be as cheap as coal gas at 5*s.* 6*d.* per 1,000 feet.

At the factory of Gerstewitz, near Weissenfels, oil gas is used to the extent of 880,000 cubic feet per annum. The gasification is attended with a production of 26 to 33 per cent. of tar, which by rectification yields 1·33 per cent. of benzole, 1·9 of chemically pure naphthaline, and 65 per cent. of condensed products suitable for conversion into gas at the rate of 780 cubic feet per cwt. The loss of gas in the pipes does not exceed 1¾ per cent., owing to its high density and the low pressure required at the burners.

A single retort, with a gasholder of 375 cubic feet capacity, suffices for the supply of thirty to seventy burners, or up to one hundred with the gasometer volume increased one-half. Two retorts, with 1100 cubic feet of gasometer space, supply one hundred to two hundred burners. The cost of the entire apparatus in the first case is £65; in the second, £90; and in the third, £137 10*s.* (the mark taken at one shilling).

Oil gas plant of the above description has been supplied to thirty-five establishments, principally in France, with a total of six thousand burners, by C. W. Schumann, of Weissenfels; and to seventy-four (up to July 1874) by P. Suckow and Co., of Breslau, the latter including gasworks for six towns, fifty-eight factories, and one lignite mine.

H. B.

On the Magnetic Constants of Nickel. By M. Wild.

(Bulletin de l'Académie des Sciences de S. Pétersbourg, vol. xxiv., pp. 1–35.)

The following investigation was made upon a nickel magnet, prepared by Joseph Wharton, of Philadelphia, and presented to the Author by P. Kotschubey, President of the Russian Technical

Society. It is in the form of a flat bar with pointed ends (2 millimètres thick, 9·5 millimètres broad, and 155 millimètres long), with an agate cap in the centre for suspension on a pivot. The weight is 25 grammes without the cap.

The knowledge of the magnetic properties of this metal is somewhat indefinite. According to Biot the permanent magnetism of a nickel needle is only one-third of that of one of steel of similar size. Lampadius determined the attractive force of a magnet on equal-sized masses of nickel and iron to be as 35 to 55, and Gay-Lussac considered the momenta of induction by a magnet on nickel and iron to be to each other as 1 to 2. Lastly, Arndtsen found that the momenta of induced and temporary magnetism in nickel are not susceptible of increase by augmentation of intensity in the magnetising power, beyond a maximum which is soon reached, and that the former is to the latter as 205 to 94.

In the present series of experiments the comparisons were made with a steel magnet, belonging to a unifilar magnetometer by Krause, which was nearly of the same weight (30 grammes), and of about the same dimensions as the nickel magnet; and subsequently with three others of Wolfram steel; the angle of deviation of a compass needle by the deflecting influence of the different magnets acting at right angles to the magnetic meridian at a uniform distance of 300 millimètres, forming the standard of comparison. By analysis the nickel was found nearly but not absolutely pure; it was free from copper, manganese, and cobalt, but contained 0·33 per cent. of iron. The experiments included determinations of the specific magnetic momenta of the bar, under the following conditions: 1, as received; 2, immediately after remagnetisation; 3, two days after remagnetising; 4, after two months and a half; and, 5, after alternate heating and cooling—the latter being for the purpose of determining the temperature co-efficient. The relation of the permanent to the temporary magnetism was obtained by comparing the deflection produced by the nickel bar when employed at the core of an electro-magnetic helix, which was alternately put in and out of the circuit of a battery of known intensity; another term of comparison being obtained by the substitution of a soft iron bar of the same weight under similar conditions.

The absolute magnetic momentum of any particular magnet is found by the following formula, which is sufficiently exact for the purpose. In it M = intensity of the horizontal component of the earth's magnetism, which in absolute measure (millimètre, milligramme) at St. Petersburg = 1·64, E = the distance of the deflecting magnetic from the pivot of the compass = 300 mm., and V = angular deviation produced.

$$M = \tfrac{1}{2} H.E^3 \tan V = 221 \cdot 10^5 \tan V.$$

From this the reduced value per unit of weight (in this case 1 gramme) is obtained by dividing the value found for M by the weight of the bar in grammes. This affords a standard of com-

parison between bars of different sizes when the disparity in weight is not very considerable.

The following is an abstract of the principal observations:—

Metal	Nickel.		Steel.		Wolfram Steel.	
Weight = w	25 grammes up to Exp. 3. 24 grammes subsequently.		30 grammes.		28 grammes.	
State	v.	$\frac{M}{w}$.	v.	$\frac{M}{w}$.	v.	$\frac{M}{w}$.
	°		°		°	
Original condition . .	7·2	112,000	18·5	245,000	..	..
Remagnetized . . .	12·0	188,000	26·5	368,000	..	..
Two days after remagnetizing	10·9	170,000	26·4	366,000	36·9	594,000
Seventy-six days after remagnetizing . . .	7·2	116,000	25·7	355,000	36·2	579,000
Remagnetized second time	10·6	173,000	..	..	..	..
Three days later . . .	9·5	154,000	..	..	36·2	579,000

The temperature co-efficient (μ) was determined from observations of the difference in deflection produced by alternately heating and cooling the bar in water through a range of about 30° by the following formula:—

$$\mu = \frac{\sin(\psi_2 - \psi_1)}{(t_1 - t_2)\tan\frac{\psi_1 + \psi_2}{2}}$$

ψ_1 representing the smaller angular deviation at t_1° the highest temperature, and ψ_2 that at t_2° the lower temperature. The first observations on the nickel bar gave for $t_1 - t_2 = 30°{\cdot}5$ a mean value of $\psi_2 - \psi_1$—

For raising temperature . . . 11′ 42″
And for falling temperature . . 9′ 8″

The corresponding values of μ per 1° C. being in the first case 0·000623, and in the second 0·000487. A subsequent comparison with the Wolfram steel bar gives

For nickel . . . 0·000472
„ Wolfram steel . 0·000382

The results of the experiments are summed up as follows:—

1. Pure nickel, contrary to the behaviour of the analogous metal, iron when pure, is susceptible of being permanently magnetised in a notable degree. But the maximum of such magnetism is only from one-half to one-third of that which is retained by hardened steel under similar conditions, according to the quality of the latter.

2. The magnetism so retained in nickel is less permanent than that of good hardened steel; the slow loss of magnetic power, whether by efflux of time or by alternate heating and cooling, being proportionately greater in nickel than in steel; and this

holds good even when the bar, by repeated heating and cooling, has been brought into a certain condition of magnetic permanency.

3. The temperature co-efficient of a nickel magnet in the latter condition is but slightly larger than that of one of good hardened steel.

4. The temporary magnetism of pure nickel is about double that of its permanent magnetic momentum, one-half of that of hardened steel, and one-quarter of that of soft iron.

The magnetic qualities of nickel are, therefore, inferior to those of iron and steel.

The Author was unable to state whether the nickel magnet in question had been subjected to hardening or any analogous process for the purpose of increasing its coercive power, but he does not think it likely that it had, because the quantities expressing its permanent and temporary magnetic momenta are very similar to those previously obtained by Arndtsen.

H. B.

New Mode of Duplex Transmission. By O. Morel.

(Annales télégraphiques, 1877, pp. 401–405.)

Duplex transmission, based upon the differential system, presents the following inconvenience: if the resistance of one of the differential circuits alters, the current augments in the one and diminishes in the other. Now these two effects combine, and consequently this kind of transmission is more affected than the ordinary transmission by the variations of the resistance of the circuit. The Author states that he has sought to remedy the defect in the following manner:—

Two relays, the one with a polarised armature, have their coils in circuit with one pole of a local battery and with the line, the polarised relay being next the line. An operating key is connected to the circuit between the two relays. The armature contacts of the relays are connected through a local battery, the poles of which battery are also connected through the coils of the receiving instrument. The contact levers of the two armatures are connected to earth.

From the description it is easy to see that so long as the levers of the two armatures are in connection with their contacts no current will pass through the receiving instrument, and if either of these levers quits this position, the circuit of the local battery will be closed in the receiving instrument. The lever of the operating key, when at rest, communicates with earth, when it is depressed or raised neither of the relays acts; but in both cases the circuit of the line battery is closed from traversing the bobbin of the unpolarised relay, the armature of which remains always attracted. For the other part, the polarised relay is previously arranged in such a manner that the passage of the current from the line battery does not cause the displacement of its armature.

A station will then be able to transmit without reproducing its signals on its own receiver, and this receiver will nevertheless receive the signals of the station corresponding.

The batteries at the two stations presenting to line poles of the same name, if the operating key at one end is at rest, the current from the opposing station will produce an effect upon the polarised relay inversely to that of the battery at its own end of the line, and its armature is displaced by, and the receiver will reproduce the signals made by, the station corresponding.

If the two stations work simultaneously, the currents emitted annul themselves, and the armature of the unpolarised relay ceasing to be attracted, the receiving instrument will still reproduce the signals sent by the opposing station. The experiments that the Author has made with the Morse have been successful, and show that the return current does not produce important perturbations; and, in fact, the polarisation of the relay nearest to the line having been over-excited by the passage of the current of the line battery, the return current has no other effect than re-establishing the magnetism to its normal state. This system does not absolutely necessitate the use of a condenser. Though the different actions of the relays are made in a satisfactory manner with the Morse, they are not produced with sufficient strength to allow of their application to the Hughes receiver. There are, at certain times, delays that can be avoided only by making the relays more sensitive, and in this case the equilibrium is very unstable. The Author has also tried the following arrangement. The receiving instrument has a double coil, the one in circuit from the transmitter (mechanically stamped paper) to line, the other in circuit from the transmitter to one pole of a battery, the same pole of which is also connected to the transmitter through a rheostat, the other pole of the battery is connected to earth. The lever of the transmitter when in repose is in connection with an earth contact, and the circuit of the battery is closed locally. One part of the current passes by the helix between the battery and the transmitter, the other part by the rheostat, or shunt, also placed between the battery and transmitter. This shunt permits the augmentation or diminution, at will, of the force which keeps the armature attracted. When the lever of the transmitter is raised, the current goes to line by traversing the helix in circuit between the transmitter and line in such a manner that the armature remains attracted. It results, that one is able to transmit without receiving his own transmission. When the two stations transmit simultaneously, currents are annulled and the armature raises itself. When the opposing station alone transmits, its current traverses the helix in circuit between the transmitter and line in an inverse manner to that of the battery at its own end, and the armature is still raised. They will receive, in the two cases, the transmission from the station corresponding; but the return current also releases the armature.

The Author states that he has remedied in a certain measure this inconvenience by regulating the shunt in a manner to make

the magnetisation produced by the local circuit inferior to that of the line circuit. The return current is then employed to destroy the excess of residual magnetism.

P. H.

Proportions of Electro-magnets. By T. DU MONCEL.

(Comptes-rendus de l'Académie des Sciences, vol. lxxxv., pp. 466–71 and 652–658.)

The deductions formulated by the Author in his last note upon maxima conditions for galvanometers[1] can be applied to electro-magnets. If in equations expressing the values F and A of the magnetic moment of the electro-magnet, and of the attraction produced, the quantity representing the diameter c of the core of the electro-magnet is varied, and an algebraic relation established between this quantity and the thickness a of the helix, which is easy, because the helix can be supposed to be wound on the iron core itself then, by placing the electro-magnet in its conditions of maximum with relation to the resistance of the exterior circuit, there can be obtained an expression susceptible of a maximum such that the relation of R to H may be that previously established or that generally admitted, or even that deduced by Weber, when there is taken into consideration the depth of the insulating covering of the wire, the relation of which is fixed by the law that the resistance of the helix should be to that of the exterior circuit as the diameter of the bare wire is to the diameter of the same wire covered. Representing by a either of these three relations, and supposing the thickness a of the helix invariable, and consequently the number of convolutions t, the attractive force A and the magnetic moment F have for expression, according to Müller's law,

$$F = \frac{g^2 E \sqrt{c}}{a \pi b a (a + c)}; \text{ and } A = \frac{g^4 E^2 c}{[a \pi b a (a + c)]^2},$$

which are susceptible of maxima with relation to c; but the quantities R and H are then supposed to vary at the same time, and in measure as the helix is elongated proportionally as the diameter of the magnetic core is increased. If the derivatives of the preceding expressions are taken with relation to c considered as variable, and equated to zero, the conditions of maximum are $a = c$, that is to say, the equality in width of the bobbin and diameter of the iron of the electro-magnet. Defining the limitation of Müller's law, the Author shows that direct experiment proves these deductions, and that there is advantage in winding electro-magnets in such a manner that the width of the layers should be equal to the diameter of the iron core, this diameter being so

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 307, where the designation of the letters is given.

proportioned to the electric intensity acting on the core that sufficient magnetism to approximate to the point of saturation is developed. This point of saturation has been defined by Müller in his researches on this question. Among the advantages of the law is the considerable simplification of the calculation of the elements of construction for electro-magnets. The expression for the length of the wire on the helix becomes $\frac{2\pi b c^2}{g^2}$, and if the length b of the electro-magnet is made a function of the diameter c by multiplying this by a co-efficient m, which calculation shows to be 11, the expression becomes $\frac{2\pi c^3 m}{g^2}$, or $\frac{75{\cdot}4\, c^3}{g^2}$, in which there are only the two quantities c and g to be considered. These may be determined according to the different cases that occur by means of the formulæ

$$c = \frac{E}{\sqrt{R}}\, 0{\cdot}172175, \text{ and } g = \sqrt{f\sqrt{\frac{c^3}{R}}\, 0{\cdot}00020106}.$$

The number of convolutions is then given by $\frac{12 c^2}{g^2}$.

For a considerable time it has been the practice to make electro-magnets of small dimensions, such as those used in telegraphy, of a length equal to six times the diameter of the core; and Hughes' experiment confirmed this rule. But, in fact, this conclusion, which gives to the double branches of a horse-shoe electro-magnet a length equal to twelve times that of the cores surrounded by the coils, cannot be deduced as to maximum of effect produced from known laws of electro-magnetic forces. From an exhaustive investigation and experimental research the Author concludes, that the dimensions to be given to an electro-magnet should essentially depend upon the electric force which acts on it, and upon the resistance of the circuit in which it is interposed. When the circuit is long and the electric source of small energy, it should be long and of small diameter; when, on the contrary, the circuit is short and the electric force intense, the core should be of large diameter. For circuits of equal resistances the diameters of the electro-magnets should be proportional to the electro-motive forces. For equal electro-motive forces the diameters should be in inverse ratio to the square roots of the resistances of the circuits, comprising the resistance of the batteries. For equal diameters the electro-motive forces should be proportional to the square roots of the resistances of the circuits. For a given electro-motive force, and with electro-magnets placed under maximum conditions, the electro-motive forces of the batteries should be proportional to the square roots of the resistances of the circuit.

P. H.

On a Common Law in Reference to Electric Induction.

By R. CLAUSIUS, Hon. M. Inst. C.E.

(Annalen der Physik und Chemie, new series, vol. i., pp. 493–499.)

There are already manifold laws of reciprocity in reference to mutual induction between two electrical conducting bodies. The Author believes that the following enunciation is new, and that the laws of reciprocity are consequent therefrom.

Let there be given any number of conducting bodies, C_1, C_2, C_3, &c., which influence one another. These become charged with electricity in two distinct ways. By the first charge let there be upon each single body the quantity of electricity represented by Q_1, Q_2, Q_3, &c., and the corresponding potential of the bodies by V_1, V_2, V_3, &c.; and by the second charge let the potentials and quantities of electricity be q_1, q_2, q_3, &c., v_1, v_2, v_3, &c. Then the following equation will hold:—

$$V_1 q_1 + V_2 q_2 + V_3 q_3 + \&c. = v_1 Q_1 + v_2 Q_2 + v_3 Q_3 + \&c.;$$

or substituting the summation sign,

$$\Sigma V q = \Sigma v Q.$$

P. H.

The Dynamo- and Magneto-Electric Machines of the Lontin System.

(Annales du Génie civil, 2nd series, vol. vi., pp. 137–148.)

The Author describes a magneto-electric machine in which upon a central axis is mounted radially a series of electro-magnets. These electro-magnets have the whole of their bobbins connected in one continuous circuit; from each connection between two bobbins a wire is led to a segment of a cylindrical commutator, there being as many segments of the commutator as there are radial electro-magnets. Each electro-magnet is capable of forming a separate inductor, or the whole series may form one powerful inductor, the current of which may be taken from two brushes, or from as many brushes to form separate circuits as there are radial electro-magnets or segments on the commutator. The outer poles of the radial electro-magnets are caused to revolve by rotation of the axis between the positive and negative poles of a powerful horseshoe electro-magnet.

The novelty of the system lies in the production of as many separate current-circuits as there are radial electro-magnets, by which means as many electric lights can be produced from one

machine as there are circuits; or a single electric light of concentrated power may be obtained from the entire circuit of the whole number of radial electro-magnets. Further it is an advantage of this machine that it may be used as a motor actuated by the current produced by another dynamo machine.

P. H.

On the Theory of Screw-Propellers. By C. Szily.

(Der Civilingenieur, vol. xxiii., p. 177.)

After quoting Redtenbacher to the effect that "A rational method in the construction of screw-propellers is not known, and that it has hitherto been impossible to deduce the best form of the blades from mechanical laws;" and Rühlmann, "As regards the present form of the screw-propellers, theory leaves us entirely in the dark as to their determination .... and thus it is that nearly every maker of screw-propellers has his own forms, all founded more or less on empirical rules;" the Author makes an attempt to obtain a useful theory in applying the differential calculus to the problem of the screw. His problem is:—

A surface, plunged into water, rotates with constant angular velocity round an axis which moves in a straight line at a constant velocity. The water, in consequence of its resistance, exerts a pressure upon each part of the surface of the propeller, the direction of which falls in the perpendicular to the surface, and the magnitude of which is proportional to the surface and the square of the normal velocity. Between given limits find the surface on which the pressure of the water in the direction of the forward movement is a maximum or a minimum. Friction is disregarded.

With the aid of a diagram the Author produces a lengthy series of highly complicated algebraic formulæ, from which he draws the following deductions:—

1. The task of determining that surface which, rotating in water and moving forward simultaneously, is subject to a maximum of pressure from the water in the direction of its forward movement, leads to a highly complicated differential equation, the solution of which seems at present to be met by insuperable difficulties.

2. Among conoidal surfaces the Archimedian screw only can give the best effect, because it alone fulfils the conditions of the maximum and minimum.

3. The angle of inclination of the most effective conoidal-surfaced screw depends upon the relation between velocities of rotation and forward movement. Other angles of inclination would have to be given to the screw when at sea, or up or down the current.

4. On starting the conoidal screw in still water the angle of inclination should not be less than 22° 39′ 27″, otherwise its effect is not only not a maximum, but absolutely a minimum.

A. H.

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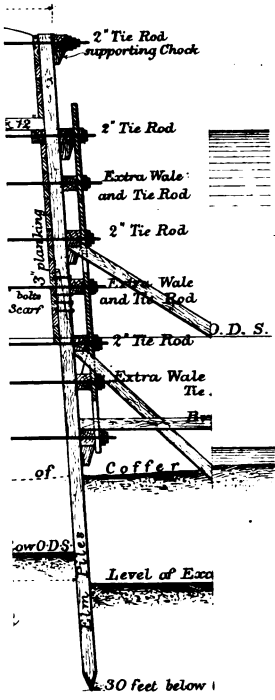

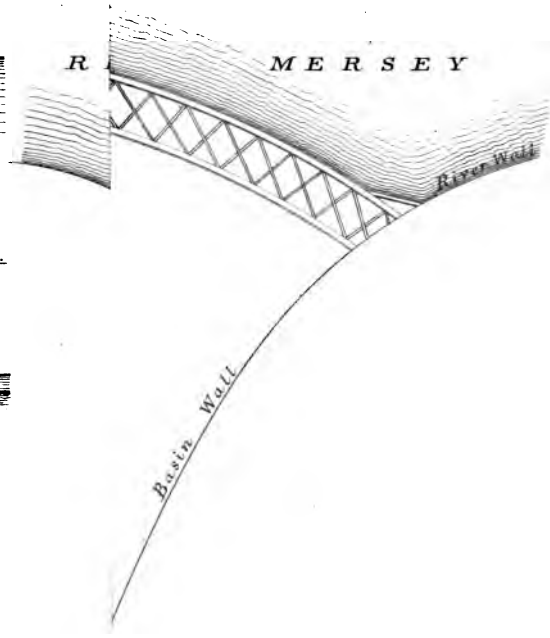

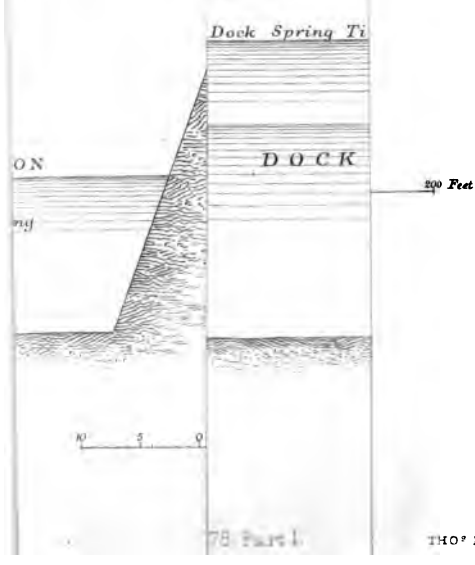

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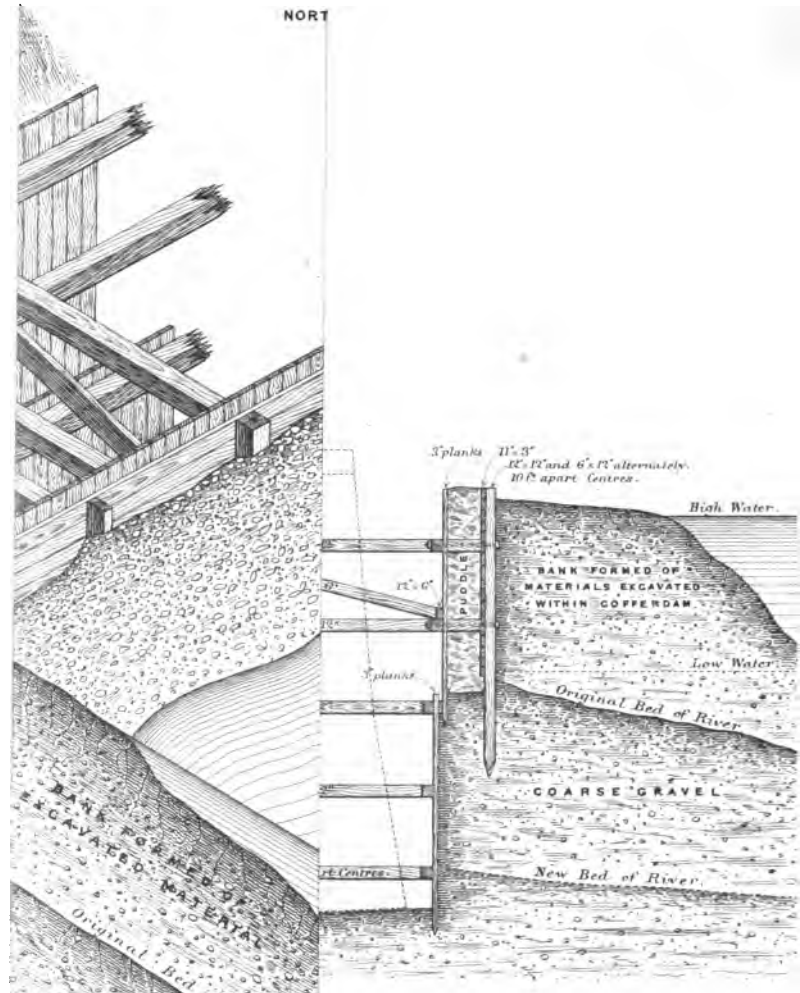

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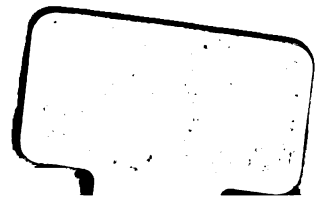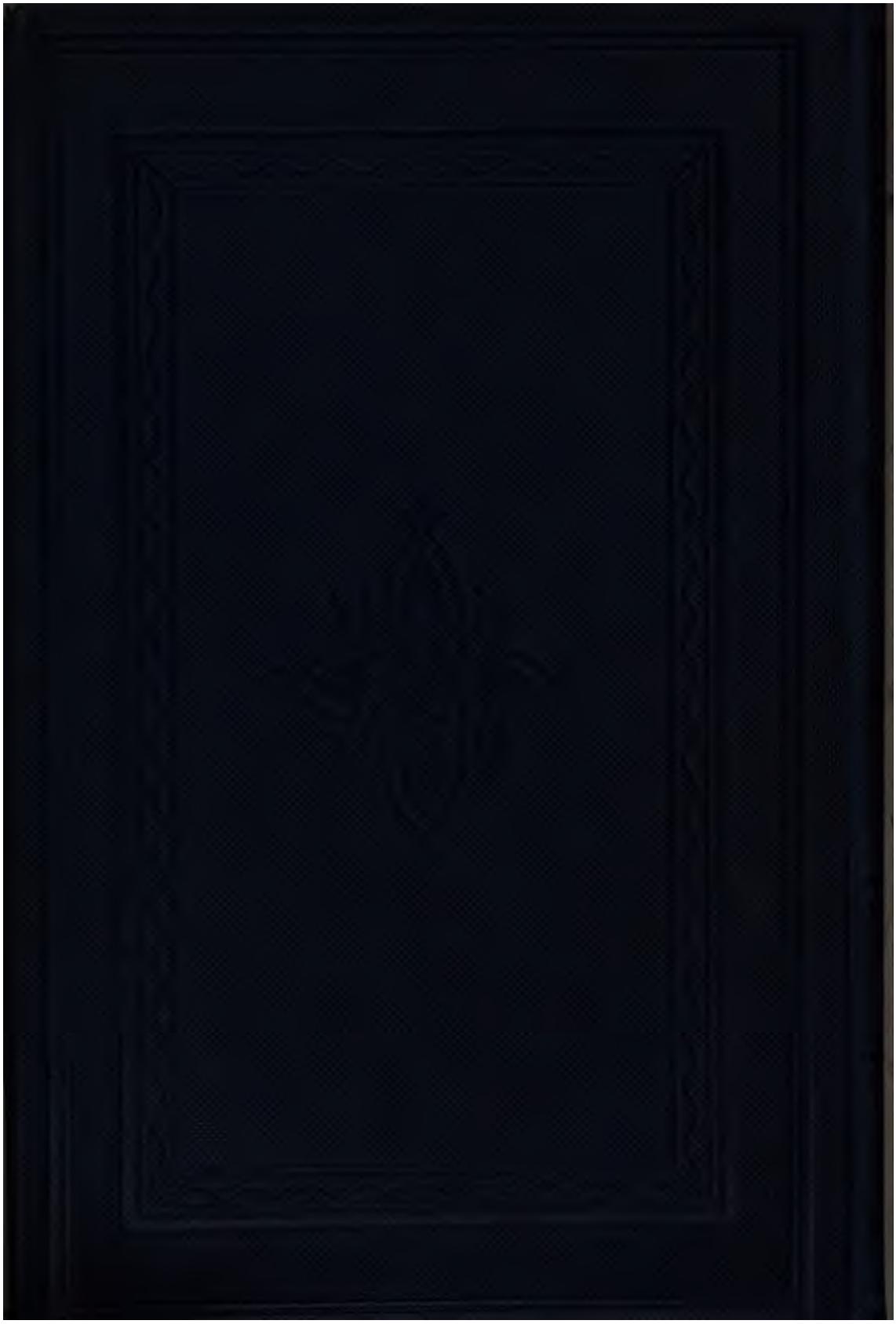
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